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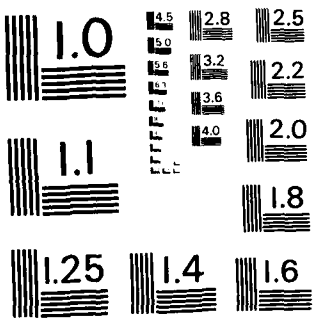
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AD-A142 412

Noise as a Public Health Problem

Proceedings of the Fourth International Congress

Volume 1

Editor

Giovanni Rossi, M.D.

EDIZIONI TECNICHE A CURA DEL CENTRO RICERCHE E STUDI AMPLIFON

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. Report Number EOARD-TR-84 08	2. Govt Accession No. A142412	3. Recipient's Catalog Number
4. Title (and Subtitle) FOURTH INTERNATIONAL CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM		5. Type of Report & Period Covered FINAL SCIENTIFIC REPORT 21 - 25 Jun 83 (Conference Proceedings Vols 1 and 2) 6. Performing Org. Report Number
7. Author(s) Giovanni Rossi		8. Contract or Grant Number AFOSR 83-0204
9. Performing Organization Name and Address Department of Audiology Turin University 3, via Genova 10126 Torino, Italy		10. Program Element, Project, Task Area & Work Unit Numbers 61102F 2301/D1 169
11. Controlling Office Name and Address European Office of Aerospace Research and Development (EOARD), Box 14, LSB FPO New York 09510		12. Report Date November 1983 13. Number of Pages 1,300
14. [illegible] Address EOARD, LSB, Box 14 FPO New York 09510		15.

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

18. Supplementary Notes

19. Key Words
noise pollution, acoustic physics, performance, behavior, nonauditory physiological effects, noise-disturbed sleep, noise measurement, occupational noise standards

20. Abstract
The program for the conference was organized around the following eight working groups: 1) Noise-induced hearing loss, (2) noise and communication, (3) nonauditory physiological effects induced by noise, 4) influence of noise on performance and behavior, (5) noise-disturbed sleep, 6) community response to noise, (7) noise and animals, and (8) noise and other agents (physical and chemical). Each group provided a broad review of research in their respective area followed by invited papers on recent advances. At the end of each session either the chairman or a designated individual summerized the session and proposed directions for further study. Additional papers not falling under the above categories were presented in a separate session. Topics in this group included noise measurement, noise reduction, and expense of controlling noise.

FORM 1473

Proceedings of the Fourth International Congress on Noise as a Public Health Problem

Volume 1

The Fourth International Congress on

«Noise as a Public Health Problem»

has been held in Turin, on the premises of the «International Centre for Advanced Technical and Vocational Training (ILO-BIT)», from 21 to 25 June 1983

with High Patronage of

SANDRO PERTINI
President of the Italian Republic

with Patronage and Official Participation of the

World Health Organization
International Labour Office
Commission of the European Communities
International Organization for Standardization
Italian Ministry of Health
Italian Ministry of Labour and Social Welfare
Government of the Piedmont Region
University of Turin
Health and Social Welfare Office, Piedmont Region
Italian Audiology Society

Proceedings of the Fourth International Congress on

Noise as a Public Health Problem

Turin, Italy
June 21-25, 1983

Volume 1

Editor

Giovanni Rossi, M.D.

Edizioni Tecniche a cura del
CENTRO RICERCHE E STUDI AMPLIFON
Milano, Italy
Novembre 1983

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WELCOME SPEECH

G. Rossi

Department of Audiology, Turin University, Turin, Italy

Dear friends and colleagues, ladies and gentlemen,

Somewhat more than eight years ago - at 6 p.m. o'clock on 10th June 1975, to be precise - I brought to a close in this city, but at another place, the international congress on "Man and Noise". On that occasion, I said:
"Tomorrow we shall return to our own lives, and our own work. I hope that the memory of these four days, and of this beautiful,industrious city, will never fade, and that it may inspire in each of us the certainty that there is even now the will to face up to definite practical problems, and solve them in the light of our current scientific knowledge, without in any way lapsing into idle, purposeless demagoguery. All this may occur through the transposition onto the practical plane of theoretical notions, and this in turn should give rise to undeniable benefits for our society. Yet it has as its inescapable corollary the need to compare, at a given moment, the progress achieved in the meantime. When shall we be able to do this ? Today I cannot say, but I am sure we shall do so in a few years' time".
God willing, then, the hope expressed eight years ago is about to materialize. Turin is once again playing the host to leading men and women

of science from all over the world, gathered together in this magnificent setting placed at their disposal by the Turin City Council and the International Labour Office, for an examination and a discussion of the state of the art with regard to man's struggle against one of the modern world's greatest and most insidious pollutants: noise.

Each aspect of this many-faceted question will be investigated in these coming days, as was done at the previous congresses held by the International Commission on the Biological Effects of Noise in Washington in 1968, and at Dubrovnik and Freiburg in 1973 and 1978. I feel sure that the fruits to be garnered from the work of this Congress will not disappoint our hopes nor our expectations.

The organisation of an international meeting of such a compass was bound to be neither simple nor easy. I have never had any illusions on that score. Yet the eagerness and generosity with which both public and private, national and international bodies and organisations have met my needs have enabled all the obstacles encountered in these years to be overcome.

These bodies and these organisations have been thanked individually on the congress programme. Allow me, then, on this occasion,to mention none of them by name, but to renew the expression of the full recognition of their contribution felt by the organising committee, and its president in particular.

It is on behalf of the committee, then, that I wish to proffer a cordial and affectionate welcome to all those attending this congress, with the hope that their stay in this city of ours may add to their store of pleasant memories.

Special problems engendered by noise pollution in the fields of acoustic physics, biology, psychology, engineering, and economy will find on the programme the ample space that becomes their importance and their worth. I am referring in particular to subjects of a medical and biological nature, which seem at last to have finally found their proper

place in a field that has hitherto been primarily approached from the physical and technical standpoint.

The complexity of many of the problems to be dealt with in these next few days will mean that no final solution can be expected. The path of progress, however, is a series of episodes, some of them victories, others disappointing defeats. What counts is the will to pursue the course embarked upon with absolute conscientiousness and an equally deep degree of humility, but above all with the determination not to hanker after the impossible, even though what is impossible today may - perhaps as early as tomorrow - take shape as a new and vibrant reality.

PREFACE TO THE FOURTH INTERNATIONAL CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM

Tobias, J. V.
Chairman, International Commission on Biological Effects of Noise

Naval Submarine Medical Research Laboratory, Groton, Connecticut, United States of America

My speech today serves as a preface to the Congress: I want to talk with you about the form and the content of the meetings.

But first, on behalf of the International Commission on Biological Effects of Noise, let me greet you on the occasion of the Fourth International Congress on Noise as a Public Health Problem. Welcome to our honored and distinguished guests. Welcome to the participants in this Congress. Welcome to you all. Thank you for being here with us. Your presence makes the Congress important.

We offer special thanks to the Italian Government, to the Piedmont Region, to the City of Turin, and to the University of Turin for their patronage, for their assistance in making this meeting possible, and for having given us such a beautiful City and such a beautiful Region and such a beautiful Country in which to meet. It is a privilege and a joy to be here.

The program this week is organized around the eight working groups that define the ICBEN and its interests. Each of these eight International Noise Teams is composed of approximately ten scientists who are renowned for their expertise in the area in which that Team works. Normally, no more than two members of a Team have the same nationality, so the groups are truly international in their membership as well as in their viewpoints.

During the next few days, you will hear some of the results of the work that the Noise Teams do, and you will meet most of the chairmen and cochairmen. In the meantime, here is a preview of the Congress.

The ICBEN believes that research workers and the people who use the results of research have too little opportunity to confer with each other. Yet even when research providers and research consumers do meet, they often discover that they have trouble understanding each other's needs. One purpose of these Congresses is to foster communication among the organizations that find noise a potential problem, the decision makers who regulate workplace noise and environmental noise, and the scientists upon whose work the regulations and the solutions to the noise problems need to be based. We are dedicated not only to learning all we can about the public health problems associated with noise but also to exchanging knowledge with people in industrial and governmental work--people with whom we ought to cooperate symbiotically.

In order to set the tone for the Congress and in order to facilitate our listening to and understanding one another,

an introductory session has been organized for this afternoon; in it, national and international organizations can share information about their agencies' needs with research workers who are likely to be able to help to provide answers. Following that session, we will begin to consider new and recent research on noise effects.

Tomorrow morning we will hear the first in the series of research reports that make up the body of the Congress; we begin with Team 1, whose presentations are centered on noise-induced hearing loss. The Team chairman is W. D. Ward of the United States and the cochairman is H.-G. Dieroff of the German Democratic Republic. Their session, like all of the Team sessions, is preceded by a broad review of research that has been done in this field of study since 1978, when the Third Congress was held. For Team 1, the review will be given by chairman Ward. Most of the rest of the session, like all of the Team sessions, will be given over to invited papers on recent advances. Then, at the end of the session, the chairman and cochairman will summarize what has been said, will add information and ideas developed by their Team, will note governmental, industrial, and research problems that are likely to arise in the next few years, and will propose directions for study.

Most of the rest of tomorrow is scheduled for Team 7, whose work deals with noise and animals. The chairman is R.-G. Busnel of France; the cochairman is J. L. Fletcher of the United States. Fletcher is giving the review in this topic.

At the conclusion of the platform presentations, the first of the poster sessions will open.

On Thursday morning, Team 4, which works with the influence of noise on performance and behavior, is scheduled. The chairman is E. Gulian of the United Kingdom and the cochairman is S. Cohen of the United States. The review paper will be given by D. E. Broadbent of the United Kingdom.

Later in the day, Team 3's area of work is scheduled. They specialize in nonauditory physiological effects induced by noise. The chairman is J. H. Ettema of the Netherlands; the cochairman is G. Jansen of the Federal Republic of Germany. S. Rehm of the Federal Republic of Germany will present the review for Team 3.

The work of Team 8 centers on interactions between noise and other agents, both physical and chemical. We have seen comparatively few studies in this area during recent years; the research will be reviewed by O. Manninen of Finland. Interest and work in this important field seem likely to expand soon.

Again, the last meeting of the day will be the poster session.

Friday's program is devoted to sleeping and speaking. First on the schedule is Team 5, which works on noise-disturbed sleep. The chairman is A. Muzet of France; the cochairman is B. Griefahn of the Federal Republic of Germany. Muzet will give the review.

In the afternoon, Team 2, which specializes in noise and communication, is scheduled. Its chairman is J. C. Webster

of the United States; its cochairman is T. Houtgast of the Netherlands. Webster will review the English-language material; others will review the French, German, and Slavic.

The final poster session will conclude Friday's work.

Saturday begins with the program planned by Team 6, which works on community response to noise. The chairman is P. N. Borsky of the United States and the cochairman is R. Rylander of Sweden. Ian Griffiths of the United Kingdom will give the review of recent work on community reaction to unwanted or potentially damaging sound. That session will conclude the parts of the program centered on the International Noise Teams.

In the afternoon, under the direction of ICBEN cochairman H. von Gierke, a group of papers will be presented covering topics that are of such broad and general importance that they are critical to every aspect of this Congress. Clearly, they merit a separate session. These reports deal with noise measurement, with noise reduction, with the benefits that noise reduction might bring, and with estimates of the expense of controlling noise.

The final presentation will be a summary of all of the work of this Fourth Congress, to be made by G. Jansen, past chairman of the ICBEN. He has the complex and challenging job of bringing together in half an hour the concepts, the research findings, the needs, and the conclusions that a hundred people have presented, listed, recommended, proposed, complained about, defended, and discussed throughout the Congress. I don't envy him, but I know that he will complete the task admirably.

Several times during the Congress, each of the International Noise Teams will meet to discuss current problems and to propose directions for continuing, extending, and adding work in its fields of interest. Members of the Teams will, of course, be at those sessions, but visitors are certainly welcome--even if you think that you have no questions to raise or contributions to make. As always, we especially want to include people with backgrounds in industry and in government as well as those who are directly involved in performing research.

As part of my scheduled closing remarks on Saturday, I will provide two or three minutes to each Team chairman so that that person can summarize or list his or her Team's recommendations for activities to be undertaken during the next five years. Although the available time will be short and the number of words few, the importance of those closing comments from the chairmen may well be as great as anything we accomplish here this week.

Now let me end this speech as I opened it: welcome to the Fourth International Congress on Noise as a Public Health Problem. Welcome, honored and distinguished guests. Welcome, participants. Welcome, all. Thank you for being here with us. It is a privilege and a joy to be here with you.

Introductory Session

Noise as an International Public Health Problem

Chairman: J.V. Tobias (U.S.A.)
CoChairman: H.v. Gierke (U.S.A.)

NOISY COMMUNICATIONS

Tobias, J. V.

Naval Submarine Medical Research Laboratory, Groton,
Connecticut, United States of America

The ceremonies are over and we must begin our work. The work of this Congress is intended not only to encourage international cooperation in the study of biological effects of noise--although that is an important and useful purpose. It is intended not only to exchange and to disseminate information and ideas--although that too is an important and useful purpose. But more than anything else, the work of this Congress is intended to promote communication among research scientists, governmental agencies, industrial workers and managers, and, indeed, everyone WHO is concerned with noise and noise effects.

Fulfilling that aim has been and remains a terribly difficult task. People from one country who are interested in noise may not always know what is being done in another country by people who are interested in noise. That fact is not very surprising. Wnat is surprising--and distressing--is the fact that one can find the same problem without ever

crossing a border.

In any country, the laboratory, factory, and government people who are most concerned about the biological effects of noise often do not say much to each other. Commonly, the lack of communication results from their not knowing of each other's existence. But too frequently, it results from their not being able to understand each other's needs--and much of the time the reason is that they do not understand each other's vocabularies.

In this Congress, beginning now, we have an opportunity to lower some of the communication barriers that keep the research worker, the industrial manager, the international commissioner, and the governmental official from speaking more clearly and more frequently to each other. Industrial and governmental workers need to know which problems are being worked on by researchers. Research workers need to know which problems are troublesome to industry and to government. But if people in industry and people in government and people in research do not say much or do not understand much when they come together, the result is a lack of well-grounded regulation and a lack of well-supported science.

In this session, we will take the opportunity to begin to talk. We will hear reports and comments on the work and interests of several international and national organizations that are concerned not only with noise but with communicating their concern about noise. During the rest of the Congress, we will hear reports and comments from research people who are also concerned both about noise and about communicating. And,

at the conclusion of this week's meetings and discussions by the International Noise Teams, we will hear the Team chairmen and cochairmen report and comment on what they have heard from you research and industrial and government workers, on their evaluation of the forthcoming problems, and on what they interpret to be the needs of the next few years.

We live in a multilingual society in which people are separated by words--by the languages they speak. Shakespeare's language is not quite clear to the German-speaking reader nor is Goethe's to the Italian nor Dante's to the French nor Voltaire's to the English.

Those of us who are interested in the biological effects of noise also live in a multilingual society. The research practitioner's words are not quite clear to the regulator nor are the regulator's to the factory worker nor the factory worker's to the researcher. Let us strive during this Congress to talk and to listen more clearly.

WHO PROGRAMME ON URBAN NOISE CONTROL

van den Eijk, J.

World Health Organization, Regional Office for Europe

I. INTRODUCTION

Excessive noise in towns is not a modern problem at all! Already Schopenhauer complained about the many times that the lash of a coachman's whip had cut-off so to say the development of deep thoughts in his mind. Centuries earlier already blacksmith's workshops sometimes were banned outside city walls because of the noise they produced. It seems that even from a few thousands years before the Christian Era complaints have been registered about the unbearable noise produced in streets of a town very early in the morning by sheep driven to the market place.

No wonder, therefore, that also the World Health Organization considered noise problems relatively early. In 1966 a study by Dr. A. Bell, called "Noise", was published in the WHO Public Health Series. And in 1970 a study by Dr. J. Lang and Dr. G. Jansen was published under the title "The Environmental Health Aspects of Noise Research and Noise Control".

A more systematic approach of the problem was envisaged when in 1971 "Development of the Noise Control Programme" was published, as the result of a WHO-Working Group, a meeting of a group of experts. As a consequence

of this Programme, in 1977 "Noise Control in Buildings" was published, prepared by another Working Group.

In 1980 a publication "Noise" appeared as part 12 in the series "Environmental Health Criteria". This publication was the result of a WHO Task Group in early 1977.

In 1982 the WHO Regional Office for Europe decided to reconsider its position with respect to the noise problems and as a result of this a report "Urban Noise" will be available this year. It is the purpose of this paper to present this WHO-report.

2. PROGRAMME

The Programme proposed in the WHO-report contains 10 items. The first 4 of them are related with desirable improvement of knowledge on the effects of noise on health. They include the following targets.

2.1 Confirmation, adjustment or refinement of published limits for noise in the urban environment with respect to annoyance and with respect to teaching and office work; separately for road traffic noise, passenger rail traffic noise and goods rail traffic noise.

All existing knowledge which is available in journals, reports or otherwise should be considered and compared critically and the results should be published in a WHO-document in such a way that they are applicable by authorities and town planners.

2.2 A better knowledge of the sound levels below which no adverse physiological effects can be envisaged, also on long term and for "sensitive" groups.

To complete existing knowledge more research may be necessary. In order to achieve results which can be applied in the field as directly as possible, it is advisable that a thorough discussion is organized between experts of different countries, in order to clarify and agree on bottlenecks with respect to definitions and methodology. Such also in view of the relatively large sums of money required and of the urgent need for "solid" results. For the moment there is still too much uncertainty with respect to such levels, especially with respect to their combination with other elements of stress in the urban environment.

2.3 Better knowledge on which levels and/or types of noise influence the sleep quality adversely.

A lot of laboratory investigations have been published already. Although further laboratory research would be useful, there is a need for complementary studies on an epidemiological basis. As for the preceeding item, WHO proposes a preliminary discussion about the purpose of the work, including definitions and methodology.

2.4 Better understanding of those aspects of noise, apart from noise level, which influence the adverse effects on health.

It is known that apart from the sound level of a noise, also other characteristics are of influence for its effects on health, especially its effects on well-being. For instance, the information content of a noise is of much importance, especially if the information has an emotional character. The sound of a crying child or of breaking glass e.g. will attract attention of most people even if the corresponding sound level is

very low. Other aspects are e.g. steady state or fluctuating sound, tonal aspects, expectations for a given environment, during daytime as well as during the evening and the night. Near an airport the sound of a plane is not strange, but in an area for quiet relaxation the same sound will raise more complaints. There is a need for an authorative publication which presents the available knowledge in a practically arranged way. Also it may turn out that more research is advisable in the field as well as in the laboratory.

So far the items which relate to the effects of noise on health. Quite another aspect is:

2.5 The promotion of the effectiveness of governmental measures.

More and more governments issue regulations and laws on noise control in the urban area. There are many differences, however, and it would be profitable to have available not only a survey of those measures, but also an evaluation with respect to their effectiveness (and other experiences) in practice.

Two items have to do with the promotion of the application of noise prediction methods developed:

2.6 The first one aims at a screening of the existing prediction methods for noise in the urban environment, with a view on simpleness and accuracy.

Prediction methods for noise in the urban area now seem to be reasonably accurate for most situations. In order that town planners take

the expected noise levels into account, they need methods which are sufficiently accurate but which are also as simple as possible. Therefore screening of the existing methods in this respect and discussion of the results is important.

2.7 The second item in this category is the promotion of an international documentation system for technical noise control achievements in towns.

This relates to e.g. layout of new (parts of) towns, shielding of traffic noise by barriers etc. as well as to traffic control. The results obtained should also be included. The presentation should be as uniform as possible in order to make comparison possible and also to avoid enthusiast reports without solid basis. It is believed that such a documentation would be instructive and would efficiently promote the application of existing knowledge. The same applies to a documentation system for enforcement of governmental and police measures.

2.8 Item 8 is the promotion of existing quiet building construction techniques and equipment, including data on noise production and costs.

Such a promotion could be achieved by compilation of existing equipment and knowledge. The production method of such a documentation should include a revision every 2 or 3 years.

2.9 Item 9 has to do with the fact that although every town has noisy areas, not every town is experienced as a noisy town. This may have to do with the dimensions of the noisy areas and with the question whether sufficiently quiet areas are sufficiently near the noisy

areas. The target here is an investigation of existing knowledge on how to design towns in such a way that they are not experienced as noisy ones although in certain parts the actual sound levels outdoors will unavoidably be relatively high.

2.10 The last item of the Programme is the promotion of the attitude of the general public with respect to noise. Better techniques, calculation methods and governmental measures are not sufficient to achieve a quieter environment. Education of the general public in this respect is of invaluable importance. It is believed that it would be worthwhile if WHO would collect the valuable experience which exists already in some member states and makes it available in a suitable form.

3. EXECUTION OF THE PROGRAMME

Much research on the subject of urban noise is being done or has been done already. When trying to fill in gaps in knowledge and/or availability of reliable, useful data, WHO wants to execute the Urban Noise Programme in such a way that optimum results can be expected and that no time or money will be wasted. Close contact with several experts, research institutes and ministries which cover environmental health and hygiene will be necessary.

WHO itself has no possibilities to carry out research projects. There are three possibilities to carry out the work:

- An expert can be asked to carry out a project as a WHO consultant. Limited funds are available to cover the costs.
- A so-called consultation can be organized by WHO. In that case a small group (three or four) of experts is asked to prepare a document on basis of existing knowledge, during a meeting of a few days. Also for this purpose

limited funds are available. But as a rule additional funds provided by the government of the country where the consultation is held, will be necessary and anyway a meeting place should be provided.

- For more expensive and extensive research no WHO funds are available and therefore WHO seeks for this purpose cooperation with existing research institutes in member states, which are able and willing to carry out agreed projects in close cooperation with WHO but financed by their own budget.

In all cases the work should be concluded by a report which is designed in such a way that it is as useful as possible for the group for which it is intended. It should present a clear description of the problem investigated, the work done to solve the problem and the results obtained.

The Programme presented here is rather extensive and it may well be that due to limited resources, at least at the beginning the execution will have to be curtailed somehow. WHO hopes, however, that enthusiast cooperation with consultants as well as institutes will be possible. In each particular case modifications are possible of course, during preparative discussions of the project. And anyway a close and open communication with WHO during the execution of the work is a requirement.

GENERAL STATEMENT CONCERNING INTERNATIONAL LABOUR OFFICE ACTIVITIES IN THE FIELD OF OCCUPATIONAL SAFETY AND HEALTH WITH PARTICULAR EMPHASIS ON NOISE

Coppée, G.H.

Occupational Safety and Health Branch, ILO, Geneva

It gives me great pleasure to address this Congress and to transmit the best wishes of the Director-General of the ILO, Mr. F. Blanchard, for the success of this meeting. I would also like to welcome you heartfully in the premises of the ILO International Centre for Advanced Technical and Vocational Training on behalf of Mr. Aboughanem, Director of this Centre. He regrets not being able to do it himself but he is in Geneva attending the 69th Session of the International Labour Conference. It is here, nine years ago, in December 1974, that the ILO Meeting of Experts on Noise and Vibration was held, which prepared the ILO Code of Practice on the Protection of Workers against these risks and which discussed the content of the ILO instruments on noise and vibration. This meeting of experts was a major milestone on the way towards the adoption by the International Labour Conference, three years later, in 1977, of Convention (No. 148) and Recommendation (No. 156) concerning the protection of workers against occupational risks due to air pollution, noise and vibration. In 1975 I represented the ILO at the Congress "Man and Noise" organised within the framework of the Eighth International Medical Surgical Congress. For me it is the third time that the city of Turin and the problem of noise are associated and I am particularly pleased to address this fourth international Congress on Noise as a Public Health Problem.

The protection of workers against occupational risks due to noise is a good example where the ILO is using its various means of action in a complementary manner. There is, as I have mentioned, Convention No. 148 and Recommendation No. 156 (up to now the Convention has been ratified by 12 countries); there is the Code of Practice (this Code

has no compulsory character but it provides guidance to governments, employers' and workers' organisations); there was a symposium on the Protection of Workers against Noise organised in November 1979 in Dresden. Dissemination of information on occupational exposure to noise and its prevention is ensured by various means: through the International Occupational Safety and Health Information Centre - CIS, through the ILO Encyclopaedia on Occupational Health and Safety (a new edition in English has just been published) and through various publications of the ILO Occupational Safety and Health Series, as well as through the ILO technical co-operation activities.

Noise is also a field where international co-operation has developed in a very fruitful and complementary manner. The International Electrotechnical Commission (IEC) sets standards for measuring equipment. The International Standards Organisation (ISO) defines methods for the measurement and assessment of occupational noise exposure. The ILO Code of Practice makes reference to these international standards. WHO has published an environmental health criteria document which studies the dose-effect relationship of exposure to noise. Taking into account existing standards and knowledge on the effect of noise, the Meeting of Experts in 1974 which I mentioned earlier has defined occupational exposure limits. The Commission of the European Communities is preparing a directive on the protection of workers against noise. The WHO Regional Office for Europe, the OECD, the Council of Europe and the UN Commission for Europe have also developed important activities concerning noise and noise control which are sometimes related to work but deal mainly with community noise problems. Several employers' and workers' organisations have published studies on occupational exposure to noise, guidelines or handbooks on noise control.

The noise limit levels for the prevention of hearing impairment which are defined by the ILO Code of Practice are the following:

- depending on the degree of protection wanted, the following limit values should be determined: a warning limit and a danger limit value;

- in the light of present knowledge, the following values may be recommended: a warning limit value of 85 dB (A) and a danger limit value of 90 dB (A); these dB (A) are measured using the "impulse" scale, i.e. these are (AI) dB;

- no matter for how short a time, workers should not, without appropriate ear protection, enter an area in which the noise level is 115 dB (A) or more;

- if there are single isolated bursts of noise which can go above 130 dB (A) "impulse" or 120 dB (A) "fast", personal protective equipment should be worn;

- no worker should enter an area where the noise level exceeds 140 dB (A).

The ILO activities concerning the protection of workers against occupational risks are part of the international programme for the improvement of the working environment (PIACT) launched in 1976. Convention No. 155 and Recommendation No. 164 adopted by the International Labour Conference in 1981 contains the principles of coherent national policy concerning occupational safety and health and the working environment including the action to be developed at the national level and at the level of the undertaking.

Adequate protection of the health of workers in all occupations is at the heart of the ILO mandate. Since 1919 the International Labour Conference has adopted some 24 Conventions and 22 Recommendations concerning occupational safety and health in the working environment. The Resolution adopted in 1975 by the International Labour Conference concerning future action of the ILO in the field of working conditions and environment gave a new momentum to ILO activities in this field. This is the purpose of PIACT.

PIACT has four basic underlying ideas. The first is that problems related to working life must be dealt with by a novel approach by trying to link the different elements that are part of that life (occupational safety and health, working time, pay, work organisation, job content, social services, living environment, leisure, etc.). Then, there is the idea that ILO action in this field is essentially intended to promote and support the activities of member States, and the originality of the programme is that it links these different activities within an international framework whose purpose is to orient, stimulate and support them. A third underlying idea of the programme is the participation of all the parties and people concerned and, firstly, of employers, workers and their organisations, in putting into effect programmes for the improvement of working conditions and environment. Lastly, the act is based on the idea that the means of action available to the ILO (labour standards, practical activities, tripartite studies and meetings, dissemination of information) should be used in a systematic and co-ordinated manner.

Within the framework of this over-all approach to the quality of working life, the working environment is considered both by the ILO and also by the United Nations Environment Programme (UNEP), as an integral part of the human environment. The problem of noise very well

illustrates the importance of a comprehensive approach to the living and working environments, to the health of workers as a whole. How is it possible to make a sharp distinction between occupational exposure during working hours, noise exposure during transport to and from work, and noise exposure in the living environment? The concept of noise load to which workers are exposed is a very important issue which has been discussed both at the national level in a number of countries and also at the international level.

There are areas where occupational health and public health concerns converge. Cross fertilisation is not only possible, but important to stimulate. Noise is perhaps a particularly good example where the occupational health approach and the public health approach are complementary and may help to promote remedial actions which would at the same time improve the noise levels in the working and living environment. For example, the importance of taking noise control measures at the design stage must be emphasised. This field may be considered as a priority area for research.

Finally, I would like to underline the interest that I will take in the work of this Congress for which I formulate my best wishes for success.

COMMISSION OF THE EUROPEAN COMMUNITIES: ENVIRONMENT RESEARCH PROGRAMMES

JOINT RESEARCH PROJECTS ON THE EFFECTS OF NOISES ON HUMAN BEINGS

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INTRODUCTION

In scientific support of the programmes of action on Environment the Council of Ministers of the European Communities has adopted a second research programme on Environment for 1976-1980, then a third research programme for 1981-1985, of which the purposes are :

a) to provide for the acquisition of the scientific and technical knowledge necessary to the execution of the action programme;
b) to look for solutions to environmental problems which may be reasonably expected to arise in the medium and long term future;
c) to foster and to coordinate collaboration between national research programmes in the environmental field.

As the budget foreseen for funding laboratories is of the order of 2 to 3 % of the financial support of the Member States to their own laboratories, it was deemed preferable to concentrate the CEC support on a few projects fostering common work between laboratories of different countries in areas of interest to many EEC countries; this was initiated in 1977 by a research project on the effects of noise on sleep in the home and on performance, going on until 1984. In 1981, another pilot project for one year was investigating experimental evidence for differences between human reactions to impulse noises and to continuous noises. Then the project was rearranged and continued for two years. In the same time, a few other interesting areas were explored for possible joint projects in future research programme.

JOINT RESEARCH PROJECTS

From surveys in the noise research literature, it often appears that, although many laboratories worked on the same problems, the results are not comparable because of large differences in the experimental conditions, in the measured variables, and in the units expressing the measurements results. Only the number of units and indices used for the noise levels is so big that it is practically impossible to make a reliable conversion table between them in order to pool the results of partial researches and to increase their statistical significance.

Therefore, it was felt that an unique way of fostering international collaboration in EEC was to bring together a number of research teams accepting to adopt a minimum common experimental protocol, allowing direct comparability of their results and pooling them. This never meant that each team must have experimental conditions exactly identical with each other, that is work duplication. But before initiating their work, every team leader has to discuss and agree with all other team leaders upon an experimental protocol such that the results are expressed in a comparable way. These preparatory dicussions are often arduous and lengthy, because each team has its own equipment and scientific interests and it is difficult to modify an established custom of working and thinking. These efforts for agreeing on a minimum common protocol are finally rewarded when it is possible to combine results of different teams which seem disparate for reaching common conclusions which did not come out of individual team results. It even occurred that, afterwards, team leaders regretted themselves not to be able to draw statistically significant conclusions because of differences in the experimental conditions which did not allow to pool all results.

1) Effects of traffic noise on sleep in the home and on performance

In 1975, three experts from Belgium, Federal Republic of Germany, and United Kingdom made a review for the CEC on "Damage and annoyance caused by noise" published as EUR report stating that there were no definite data on the relation between health and noise-induced disturbance of sleep pattern. After considering the difficulties of achieving epidemiological surveys on such a subject, without first determining more

precisely possible health effects to look at, it was decided to commence a joint project on the effects of traffic noise on sleep of persons living near motorways since a long time. Between four laboratories (D, F, NL, UK), a minimum common protocol was agreed upon to be applied to volunteers normally in a noisy environment. To overcome the difficulties of comparing different persons, the reactions of each subject were recorded in their normal environment, then in a quieter environment, and again in normal conditions to evaluate differences due to changes in noise levels. A number of common physiological reactions as well as noise levels in the bed-room were continuously recorded during 10 to 20 nights per subject, performance tests were made and questionnaires were completed every morning. Each team was free to add particular measurements and to fix certain experimental conditions (f.i. the way to reduce noise level in the bed-room) provided that a minimum number of measurements be made in the same way. So far, the project is not ended, and Mr. Jurriens will present the results common to the teams in the session on "Noise and sleep" while some more specific results will be illustrated by Mr. Kumar and Mr. Wilkinson.

2) Comparison of community reactions to impulse noise and to continuous noise of the same equivalent noise energy level ($L_{A,eq}$).

In 1980, the CEC advisory committee of noise experts recommended to look for the experimental differences between the reactions of a community to impulse noise and the reactions of the same community to continuous noise (traffic noise) of the same $L_{A,eq}$ to confirm if the correction of +5 dB given in the International Standard Organisation Recommendation ISO R 1996 (1971) was appropriate or should be modified.

Before embarking on a large size project, it was preferred to have an exploratory project for one year to look at different possible reactions, physiological and psychological, with many laboratories collaborating to share the work in such a way that all results must be directly comparable. Again, it meant that all laboratory leaders had to agree with each other on the experimental design and protocol for having a minimum set of common identical measurements to which individual team results were always compared. In total, eleven laboratories (D, DK, F, I, IRL, NL, UK) joined and achieved this pilot project in three groups :

a) physiological reactions in laboratory: volunteers were listening to a succession of noises (white noise, traffic and impulse noises) for 10 minutes each and a number of physiological parameters (heart rate, respiration rate, blood and urine analysis) were recorded;

b) annoyance rating in laboratory: again volunteers sitting in a room similar to a living room were asked to answer to a questionnaire after 5 minutes exposure to a noise at a given $L_{A,eq}$. Each subject was listening to a succession of different noises at various $L_{A,eq}$ in a random order, and relative annoyance ratings were calculated on purely numerical scales;

c) field impulse noise measurements and community reactions: some specific impulse noise sources in the environment (pile drivers, shooting range, construction noise) were looked at; different ways to identify and to quantify the impulse noise levels among ambient noise levels were tried. In particular, the EEC directive n. 79/113 (published in the O.J. of the European Communities, n. L 33 of 8/2/1979) established a practical way of determining whether a sound source is impulsive or not : looking at the difference between two sound level meters readings set in "slow" and "impulse" positions, a value equal or higher than 4 dB characterizes an impulsive source. This method was found not reliable for ambient noises when a variety of sources are mixed at different levels, unless one takes only the peak value of the two meters. An opinion survey in the 10 EEC States carried out in 1981 showed that specific impulse noises from construction sites, heard by a small fraction of the population only, were given a high annoyance rating.

The results of this pilot phase for the two groups b) and c) indicated a trend encouraging enough to continue for another two year project investigating more carefully this problem. For the physiological group, the differences were not large enough to justify the continuation of the research.

In the team session "Community response to noise", Mr. Rice and Mr. de Jong will present the actual results of the two groups, annoyance rating in laboratory, and field surveys respectively.

Depending on a detailed analysis of these results, it should be decided by the end of 1983 if this joint project continues with CEC support for the next two years.

3) Other exploratory research for possible joint projects in future CEC Environment Research Programme

As the two previously mentioned joint projects requested about three quarters of the CEC budget for noise research, it was only possible to initiate preliminary work into other areas of common EEC interest.

a) cardiovascular effects of noises: two contracts were awarded to profit from epidemiological surveys, one in UK and one in Germany, to investigate some ways of future research. As epidemiological studies are long and costly, it is not possible to fund completely new ones, but it seemed worthwhile to join in nationally funded research projects which are of utmost importance due to the cardiovascular morbidity and mortality;

b) synergism between noise and vibration in transport vehicles: as an increasing number of persons may drive a car for long periods of time even for holidays, it was decided to look at the reactions of professional drivers exposed in laboratory to combination of noise and of vibration to see whether this provokes a synergistic effect, that is more than the addition of the effects of each stimulus alone. Two laboratories, one in France and one in Ireland, collaborate on this project.
As these contracts started only in 1982, no results are yet available; it is expected that the results should allow to take a decision in 1985 for funding more consequently these areas in the next CEC Environment Research Programme.

c) community reaction to aircraft noise: this is a new exploratory research to be carried out in 1984-85 around two or three major airports in EEC to determine whether an harmonization is feasible between the methods used in different countries for assessing noise levels at ground and community response with questionnaire. Actually, the methods and the noise indices adopted by the EEC Member States are incommensurable at all and it is impossible to compare the situations and the national

regulations on land use around EEC airports. Once again, it will be tried to adopt a minimum set of common measurements used as a yard-stick for all national measures. If such a common method proves to be acceptable, then future national surveys might be eased.

CONCLUSIONS

Because of the constraints on the CEC research budget on noise topic, a deliberate choice was made to concentrate the support on a few projects, rather than to scatter the available funds. The international collaboration was a major point in which the CEC role can be unique, bringing together a variety of researchers to speak to each other in a common way allowing direct comparison and addition of results. These joint projects are also of immediate interest to each participating laboratory because it may concentrate upon its specific interests in the project and still benefit of the research made in other laboratories, because of the common experimental protocol followed by every member of the project. In the same time, the confidence in the results is increased, and the variety of experimental parameters which can be studied by the different laboratories is much larger than if it were only one laboratory to do the work.

Furthermore, an important qualitative advantage of these joint projects is that every member understands better what the others want to achieve, how they work and which questions may arise to interpret partial results.

It is highly desirable that the CEC be not considered as only looking at levying taxes on each Member State, but that it can make working together more fruitful for everybody, which can be termed "Work added value".

PROTECTION OF WORKERS FROM THE RISKS OF OCCUPATIONAL EXPOSURE TO NOISE: ACTIVITIES OF THE COMMISSION OF THE EUROPEAN COMMUNITIES.

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Exposure to high noise levels is known to affect health and working efficiency; its effects range from psychological nuisance to organic damage. Protection against noise at work is thus of concern both to management and labour, and to the relevant public authorities. It has been listed under the actions covered by the Action Programme of the European Communities on Safety and Health at Work.

Loss of hearing is becoming one of the commonest recognised occupational diseases in our society today and as a result threatens a large number of workers. Numerous studies have been carried out on the effects of noise on hearing and these have enabled the risks of hearing loss to be assessed for the conditions prevailing at many work places, unlike other effects. The Commission considers that throughout the Community, workers should be afforded a protection against risks to their hearing and safety

which are due to excessive exposure to noise at the work place.

The number of persons involved, the resulting human and social costs, as well as the economic and technological constraints connected with a reduction of noise levels, mean that the problem must be tackled from various angles. For several years now, Community actions have aimed at limiting the sound emission of noisy equipment by the harmonisation of the corresponding laws. However, the health considerations have not been the overriding consideration in such legislation although aiming to reduce noise at source goes obviously in the right direction. The emission limits which have been adopted to date have not had as their primary aim the protection of hearing. If, indeed, this were to be the primary aim, then such limits would need to be established at such low levels that account is taken of the worst possible conditions, which is neither realistic nor reasonable. On the other hand, the duration of exposure and the use of collective and individual protective equipment can also play a part in giving such protection. Thus, since the damage caused to hearing depends on the quantity of noise received by the ear, the Commission concluded that limiting this noise would control the amount of hearing loss; a proposal for such a Council Directive (O.J. C289 of 5.11.82) has been drawn up accordingly. To protect hearing any action which limits exposure is acceptable but the proposal lists these in

order of priority. As already mentioned, reduction of noise emission is a first priority, with well-designed and quiet plants and equipment being the best answer. This is, however, a long-term action and there will be many cases in which the risk of hearing damage will still exist so other means of control have to be considered. These involve such factors as the modification of the organisation of work which can result in a reduction in the dose of noise received; it can also cover the use of ear defenders which should, however, be considered as a last resource due to their restrictive nature and inconvenience. The attenuation provided by ear defenders varies with the frequency of the noise and the specific attenuation factor at a given work place which can be difficult to determine. In addition, inadequate or intermittent wearing of ear protectors results in a reduced efficiency and overall the actual protection afforded by such devices is uncertain. A tendency to over-protect also introduces its own problems, and, although there is no doubt about the general efficacy of individual ear protectors, there is no doubt that they do have limitations which have to be taken into account.

In preparing a regulation of this nature, the size of the problem and the variety of situations which will be encountered have to be taken into account. In the Community 20 to 30 million people are probably subjected at work to equivalent continuous noise levels exceeding 80 dB(A) and which may therefore result in a risk to

hearing. Of these half work in places where the mean noise level exceeds 85 dB(A) and about 6 to 8 million in places where the mean exceeds 90 dB(A). To arrive at a uniform control of such widely differing situations, it is best to state at Community level the minimum health objectives that have to be attained and their application is subsequently undertaken by local authorities. This is a concept that is already utilised in the field of industrial health and safety.

There are strongly held and differing views about the level to which occupational noise should be limited. A zero risk to hearing implies that the daily noise exposure levels should not exceed 80 dB(A) which must be regarded as the target for the future. However desirable this target may be, it is unfortunately unrealistic in today's industrial situations and a balance has to be arrived at between socio and economic considerations leading finally to a political decision. The Commission has proposed that the noise limit should be at the lowest figure found in the Member States' existing regulations; the risk to hearing associated with such an exposure can be assessed and expressed as the fraction of the population which is expected to show a given social handicap resulting from a corresponding hearing impairment.

The Commission has utilised these principles in its proposal and has put forward a limit value of 85 dB(A) for the daily sound exposure level to which the ear may be

submitted at work; this is the quantity of noise delivered by a constant sound pressure level of 85 dB(A) for 8 hours. Furthermore, the peak sound pressure at the ear may not exceed 200 Pascal so that acute damage is prevented. These two values are absolute limits which should not be exceeded; they take into account, however, the effect of all the measures implemented for complying with them, including the use of hearing protectors.

If workers are likely to be exposed to levels of noise exceeding these values, then technical or organisational control measures have to be undertaken to reduce the exposure as far as is reasonably practicable. This introduces the concept of technical and economic feasibility which has to take into account the specific work situation. If this does not result in the limit values being complied with then suitable hearing protectors have to be used.

There is thus no strict limitation of the ambiant noise (except at very high levels) and the duties incumbent on the employer are to continue to reduce the noise level to a feasible amount in so far as it is likely to result in excessive exposure.

When the limitation of sound exposure is by means of hearing protectors it is foreseen in the Commission's proposal that audiometry of the workers concerned shall be performed. This, therefore, removes many of the uncertainties involved with the use of hearing protectors

and allows early identification of those individuals whose hearing is beginning to deteriorate. Remedial action needs to be taken to prevent the hearing impairment becoming significant.

The Commission's proposal does not detail which measurement methods have to be used either for determining the noise exposure or for audiometry. Such methods may be selected according to the specific situation but they should be adequate enough to determine whether or not the limits have been exceeded. This allows the use of less elaborate methods or apparatus but the uncertainties and variations resulting from such measurements must be taken into account so that the result errs on the side of safety. For site measurements this means determining the equivalent energy level which has not been exceeded, for instance at 95% confidence limits; for audiometry screening techniques identify those members of the population who have a hearing loss including some members with false negative hearing losses. However, the Commission's proposal does detail reference methods which are to be used for ascertaining the accuracy of these simplified procedures, and for use in disputed cases.

This proposal for a directive is one of the Commission's major actions for the protection of workers against exposure to noise at work but its application necessarily involves other activities amongst which figure noise characteristics of various equipment. As a sizeable

fraction of noise at work is produced by tools and machines, adequate information on the likely exposure resulting from their use is useful in determining the measures that should be taken during their operation. Furthermore, such information will also aid in the move towards the development and use of quieter equipment. The determination of the attenuation factor of hearing protectors used at the work place is another field of activity which needs to be examined more closely with the aim of establishing a Community method which can be applied in every-day working situations. Thus, there is an overall need for the standardisation of measurements.

The Commission intends to continue to review the scientific knowledge on the health effects of noise together with their practical application in today's industrial society so that appropriate proposals can be introduced in an endeavour to improve the health, safety and wellbeing of workers.

THE ACTION PROGRAMMES OF THE EUROPEAN COMMUNITIES ON THE ENVIRONMENT
- NOISE ABATEMENT POLICIES -

OLSEN, E.

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At a time when the economic situation continues to be the principal cause of concern to most governments and states, when the emphasis is being placed on the problems of inflation, unemployment, energy, etc., it may appear a luxury to discuss the problems of noise control and noise abatement.

However, this congress will once again - as other congresses have done - state unambiguously that noise continues to have deleterious effects on man and on the environment. The proportions of the noise have exceeded the limits of acceptability. It cannot be stressed too often, but already as from his foetal life man is a victim of noise, which Professor Ingerslev so rightly characterizes as an insidious poison. Noise demands in every respect as much attention as e.g. chemical waste and smoke. To elaborate this point to this audience is evidently superfluous; there is no need to preach to the converted.

The primary aim of this paper is to attempt to give the general outlines of our activities and of the Third Action Programme of the European

Communities on the Environment 1). This programme, which covers the period from 1982 to 1986, has recently been adopted by the Council of Ministers.

In the introduction it is clearly stated :
"that environmental action must not only take account of the major problems confronting the Community (employment, inflation, energy, balance of payments and growing regional disparities) but must also contribute to the efforts made in other ways to find solutions. This will be conditional on the deteriorating economic situation not being used as an excuse for weakening the environmental policy that is now under way".

Considering that a "phase down" in environmental measures, and quite especially on those related to noise, seems to be the policy adopted by a great number of governments throughout the world, this standpoint of the Community is notable.

In respect to noise the Third Programme will be a continuation of the earlier programmes and will aim to :

1 - ensure that the decisions already taken are fully implemented;
2 - monitor the effects of these measures and, where necessary, adapt them to new situations and information;
3 - consolidate the measures taken with the particular aim of making an effective contribution to the achievement of the overall strategic objectives, having due regard to all socio-economic implications.

Accordingly, the Commission will put forward a programme setting out the general framework for a body of measures which will be taken at the different levels to combat noise. The measures concerned must be specified and varied according to the types of activity that should be protected from noise (activities such as education, medical care, relaxation, rest, leisure, etc.) or regulated in order to reduce the noise they cause (transport, industry, agriculture, noisy leisure activities, etc.). The measures should not only cover the sources of noise emission but should also take into account the conditions governing noise propagation and reception (e.g. traffic noise can be limited not only by reducing engine noise, but also by the use of appropriate road-surfacing materials and better traffic planning).

This general proposal could, depending on the circumstances, lead to Community action or to national or regional programmes.

A special effort to standardize the various descriptive noise indices will be made, the initial aim of which would be to compare existing national regulations and to assess their effects on society and the economy.

Is it, by the way, sensible to have such a great variety of different indices and units ?
There is certainly a need to relate subjective response to the noise environment to some kind of a measurable aspect of that same environment. Therefore, it is understandable that it is not all that easy to simplify and put all types of noise in one basket. However, with some good will it should be possible to cut down the number and help the bothered regu-

latory officials confronted with the present proliferation of indices, units and rating scheemes.

In response to the Third Programme the Commission has taken the first actions to establish a better comparability of noise contours around airports related to different noise indices and noise scales.

As you may find this task interesting,allow me to give you a few details.

Presently, five noise indices are used in the legislation of Member States of the Community for assessing the aircraft noise exposure levels in the vicinity of airports. We had to recognize that before reaching an agreement on a harmonised index, some intermediate steps were needed, in particular the establishment of a common data bank and the definition of a common noise scale. Therefore, the objective of the Commission, as a first stage, was to provide a research informatic tool with a view to reaching a better comparability of the noise contours that are established by Member States.

The CANAR (*) Computer Program of the Commission allows for each airport the computation of the :

a) contours for 8 noise indices;
b) footprints for 4 noise scales;
c) areas of noise curves;
d) number of people who are exposed to a given noise level in a given zone.

(*) Consequences of Aircraft Noise Abatement Regulations.

The data that can be collected from CANAR can help us to solve the numerous technical, economic or political problems that may be associated with a legal use of noise contours. It should also allow us to assess the economic impact on operators of some noise abatement strategies and the ratio cost/efficiency of some specific flight procedures. It is intended to make this programme freely available. The results of this exercise thus far appear very promising and further efforts are being made to develop and expand the programme.

The encouraging results of this action open the possibilities of extending the exercise to other areas such as noise from construction sites and road traffic. Railway noise could surely also benefit from such an action.

The expansion of these programmes should, of course, be carried out without prejudice to our actions on noise abatement at the source. However, since a number of proposals for Council directives concerning noise sources are at present blocked in the Secretariat of the Council of Ministers for political reasons - closely connected with the so-called third country problem - it might be better to alter our aim slightly, until this essential problem has been resolved.

This may by now lead you to ask what are the overall, practical achievements; in what perspective should we view our activities ?

The First Action Programme 2) did not offer a comprehensive noise abatement programme but listed specific measures within the framework of the general programme for removing barriers to trade. Moreover, this was a

fairly accurate reflection of what was happening in many countries.

The priority areas consequently found broad acceptance with the competent authorities of the Member States and included :

- road traffic,
- factories and construction sites,
- aircraft,
- railways,
- household appliances.

The Commission accordingly started work on :

- motor vehicles, 1970;
- construction plant and equipment, 1975;
- aircraft noise, 1976;
- railways, 1979;
- household appliances, 1980.

Specifications for such products can be covered in either of two ways - by specifications relating to the use of a product, or by specifications to be taken into account during the manufacture of a product.

The Commission's services take the view that, in general, specifications relating to the use of a product are more appropriately pursued at the level of the national, regional or local authorities of the Member States.

However, as far as specifications to be taken into account during manufacture are concerned, the Commission's services consider that harmonisation at a European level - and, in some particularly important areas

at a worldwide level - can serve two aims; first, improved chances for environmental protection and secondly, a reduction in the possibilities of divergence between Member States (which might result in technical barriers to trade).

So far the Commission has used two differing methods for dealing with specifications to be taken into account during manufacture; these are :

- fixing of noise level limits (as, for example, when dealing with motor vehicles and construction plant and equipment);
- labelling with a noise level (as in the draft Directive on household appliances).

The Commission chooses - on a case by case basis - the method which it considers best responds to the potential impact on the Environment.

The aim of the Second Programme 3) was to ensure the continuation of the policy launched in 1973, paying closer attention to the overall increase in the level of noise nuisance; this to be achieved by means of programmes setting out the general framework for proposals concerning :

- the guidelines which the competent authorities may take into consideration when determining the levels (quality objectives) appropriate to zones, where a particular activity predominates : rest zones, residential areas, leisure areas, industrial estates, roads, railways, airports, international waterways, etc.;

- noise measurement methods;

- specifications for noisy products, measures dealing with the monitoring of the utilization of these products, rules for labelling and the affixing of labels; with the assistance of national experts, the Commission was to draw up a list of priorities with a view to tabling proposals on these matters. Such a list was to be based on an assessment of the significance of these products in the overall impact of noise on the environment;

- noise insulation standards;

- permissible noise levels at the workplace, determined in conjunction with the European Foundation for the Improvement of Living and Working Conditions and with the Social Action Programme of the European Communities;

- research into the effects of noise on man (*) and epidemiological surveys.

These latter two actions will be dealt with in details by my colleagues Mr. Van Der Venne and Mr. Guillot.

As I have mentionned, the Third Programme will be a continuation of the earlier programmes. Hopefully it will bring a leap forward in the environment field, and what is just as important, lay the firm foundations of a Community environmental policy capable of steering the Community

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(*) Especially brief or low-frequency noise

to a growth model based more firmly on considerations of quality rather than on quantity.

Allow me to add a last word : at the end of the day we are all responsible for the quality of our environment. This simple fact is often forgotten or overruled.

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INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. TC43 ACTIVITIES RELATED TO NOISE AS A PUBLIC HEALTH PROBLEM.

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INTRODUCTION

The International Organization for Standardization - ISO - is a non-profit organization whose aim is 'to promote the development of standards in the world with a view to facilitating international exchange of goods and services and to developing mutual co-operation in the sphere of intellectual, scientific, technological, and economic activity'.

The activities of ISO in the field of NOISE are undertaken by the Technical Committee TC 43 'Acoustics' and its Subcommittees TC 43/SC 1 'Noise' and TC 43/SC 2 'Building Acoustics'. Standards relating to vibrations are developed by the Technical Committee TC 108 'Mechanical vibration and shock'. Vibrations are, however, not considered within the compass of this paper.

It should be noted that Technical Committee TC 29 'Electroacoustics' of the 'International Electrotechnical Commission' - IEC - is responsible for the implementation of specifications of the characteristics of measuring instruments for acoustic

purposes. Publication 651, 1979 is a typical example of a document on measuring instruments developed by IEC.
The scope of TC 43 reads: 'Standardization in the field of acoustics, including methods of measuring acoustical phenomena, their generation, transmission and reception, and all aspects for their effects on man and his environment'.
The scope of TC 43/SC 1 is: 'Standardization in the field of noise in all aspects, including methods of measurement of noise produced by diverse sources in diverse environments and the assessment of the effects of sound on man'.
The scope of TC 43/SC 2 is: 'Standardization in the field of building acoustics, including architectural acoustics, acoustical properties of building materials and constructions, and sound propagation in buildings'.

It is important to note that it is a well-established principle that TC 43 confines its activities to purely technical problems relating to methods of measurements and the assessment of the effects of noise on man. The establishment of maximum permissible values for noise exposure is outside the scope of TC 43. The responsibility for establishments of these values rests with the national or regional authorities.
The enormous expansion during the last 25 years of the surface- and air traffic, the industrial revolution with mechanization of industry and the introduction of more and more office machines and electric domestic appliances involves that the noise exposure has increased to such a level that our long-term health is seriously threatened.

The citizens of many countries have since the late sixties demonstrated a vivid interest in noise problems. They have demanded formulation of an effective noise abatement policy for the benefit of the welfare of the entire population.
Therefore, it is of the utmost importance that the authorities understand their responsibility and establish proper maximum permissible values for noise emission and noise exposure.
The actual values chosen reflect the importance which the authorities - and through them the public - attach to the environment. The decision should be based on a comprehensive analysis which involves deliberations concerning the quality of the environment, the economical resources available, and the proper diversion of these resources to a great number of purposes. It is not unusual to carry out cost-benefit analyses when a proper balance between a number of interests shall be established.
Cost-benefit analyses in connection with deliberations regarding environmental problems should be carried out with utmost care. Such analyses may not be successful because it seems difficult - if not impossible - to evaluate in economical terms the adverse effects of noise.
An effective and proper noise abatement policy - and especially the establishment of proper maximum permissible values for noise emission and noise exposure - depends on internationally agreed standards on measurement of noise emission, noise transmission, noise exposure, and methods for evaluation of the effect on noise. It is the responsibility of ISO to develop such standards. ISO has already developed a great number of standards. It should, nevertheless, be realized that many

instrumentation and labour. The three classes are:

1. The survey method (grade 1)

   This method requires the least amount of time and equipment. It may be used for comparisons between noise sources of similar characteristics. The sound field is described by the sound level as measured by a sound level meter.

   This method is generally of limited value if corrective measures to reduce the noise are to be evaluated.

2. The engineering method (grade 2)

   In this method, the measurements of sound level or sound pressure level are supplemented by measurements of band pressure levels. The acoustic environment is analyzed to determine its effect upon the measurements.

   The engineering method provides information that is usually sufficient for taking engineering action.

3. The precision method (grade 3)

   This method gives as thorough a description of the noise problem as possible.

   The measurements of sound pressure level or sound level are supplemented by measurements of band pressure levels. Records are made over an appropriate time interval in accordance with the duration and fluctuations of the noise. The acoustic environment is carefully analyzed and the measuring points and the frequency range are selected according to the characteristics of the noise source and environment.

This category of Standards includes at present eleven standards: ISO 3740-ISO3749 and ISO 6081.

ISO 3740-ISO 3748 (1st edition 1975-1981, the two last-mentioned are at the Draft Standard level)

This series of Standards 'Determination of sound power levels of noise sources' describes various methods for determining the sound levels of machines and equipment. Sound power level data are useful for:

a) calculating the approximate sound pressure level at a given distance from a machine operating in a specified environment;

b) comparing the noise radiated by machines of the same type and size;

c) comparing the noise radiated by machines of different types and sizes;

d) determining whether a machine complies with a specified upper limit of sound emission;

e) planning in order to determine the amount of transmission loss of noise control required under certain circumstances;

f) engineering work to assist in developing quiet machinery and equipment.

When applying these basic standards to sound measurements on specific machines, it is necessary to decide which one of the basic standards is most appropriate for the particular class of machine or equipment and for the purpose of the test. It is also necessary to decide on specific details for mounting and operating the machine to be tested within the general principles stated in the basic documents. Guidelines for making these decisions are provided in ISO 3740.

The methods described in this series can be classified in three classes according to the requirements they put on the environ-

ment in which the measurements are taken, and on the amount of more will have to be developed in the years to come.

It shall especially be emphasized that the responsibility for selecting a proper physical description of noise rests with TC 43. A proliferation of descriptors resulted in considerable difficulties in establishing noise limits. ISO has selected the A-weighted energy-equivalent continuous sound pressure level in decibels as the best descriptor for estimation of the effects of noise on man.

CLASSIFICATION OF INTERNATIONAL NOISE STANDARDS

International Noise Standards can be divided into the following six main categories:

Category 1. Basic Standards on description and measurement of environmental and occupational noise plus evaluation of its effects on human beings.

Category 2. Basic Standards describing various methods for measurement of noise emitted by machines and equipment.

Category 3. Specific 'Noise Test Codes' for various types of machines and equipment.

Category 4. Standards for measurement of noise emitted by road and rail vehicles, vessels, aircraft and other means of transport.

Category 5. Standards on measurement of sound insulation and sound absorption.

Category 6. Various other noise standards.

The development of an ISO Standard is a three-step procedure. The first step is drafting of a Draft Proposal (DP). The next step is a Draft International Standard (DIS). The final step is an International Standard (ISO).

STANDARDS OF CATEGORY 1

BASIC STANDARDS ON DESCRIPTION AND MEASUREMENT OF ENVIRONMENTAL AND OCCUPATIONAL NOISE PLUS EVALUATION OF ITS EFFECTS ON HUMAN BEINGS.

This category of standards includes at present three standards: ISO 2204, ISO 1996 and ISO 1999.

ISO 2204 (1st edition 1975 - 2nd edition 1979)

This International Standard: 'Guide to International Standards on the measurement of airborne acoustical noise and evaluation of its effects on human beings' presents a summary of the methods in common use and of the methods specified in other International Standards.

ISO 1996 (1st edition 1971 - 2nd edition in preparation)

The title of the 2nd edition of ISO 1996 is: 'Description and measurement of environmental noise'. The aim of this standard is to provide authorities with material for the description of noise in community and work environments. Based upon the contents of the standard, noise limits can be specified, and the compliance with these limits for acceptability can be controlled by using the methods described in the standard. The standard consists of several parts. The present list of parts has the following subtitles:

Part 1 Basic quantities and procedures (1st edition 1982)

Part 2 Acquisition of data pertinent to land use (Draft Proposal)

Part 3 Application to noise limits and complaints (Draft Proposal).

ISO 1999 (1st edition 1975 - 2nd edition in preparation)

The title of the Draft International Standard of the 2nd edition of ISO 1999 is: 'Determination of occupational noise exposure and estimation of noise-induced hearing impairment'. This International Standard specifies a method for calculating the expected noise-induced permanent threshold shift in the hearing threshold levels of adult populations due to various levels and durations of noise exposure; it provides the basis for calculating handicap according to various formulae when the hearing threshold levels at commonly measured audiometric frequencies, or combinations of such frequencies, exceed a certain value.

The Standard applies to noise which is steady, intermittent, fluctuating, irregular or impulsive in character. In the case of impulsive noise, it is recommended that this International Standard be applied only as long as the instantaneous sound pressure at any time during the exposure does not exceed 200 Pa (140 dB relative to 20 µPa).

To calculate the risk of sustaining hearing handicap due to noise exposure, the threshold of hearing of a non-noise-exposed population of comparable age must be known. Since different criteria can be applied to the selection of this population, this International Standard allows for two possibilities presented by two different data bases:

a) an otologically normal population, that is, 'highly screened' (see ISO 7029);

b) any other population selected by the user of the International Standards as being appropriate.

STANDARDS OF CATEGORY 2

BASIC STANDARDS DESCRIBING VARIOUS METHODS FOR MEASUREMENT OF NOISE EMITTED BY MACHINES AND EQUIPMENT

Use of the precision method is required in complex situations where a thorough description of the sound field is needed.

ISO 6081 (Draft International Standard)

The title of this Standard is: 'Noise emitted by machinery and equipment - Guidelines for the preparation of test codes of engineering grade requiring noise measurements at the operator's position.'

The Standard lays down the conditions of measurement of noise at the operator's position(s) and at other specified locations in the vicinity of different types of machinery and equipment used indoors and outdoors. It also applies to operator positions which are partially or totally enclosed by the machine or are within a cab which may be an integral part of the machine or remote from the machine.

The Standard provides furthermore guidelines for the installation and operating conditions for the machinery and equipment undergoing evaluation.

STANDARD OF CATEGORY 3

SPECIFIC 'NOISE TEST CODES' FOR VARIOUS TYPES OF MACHINES AND EQUIPMENT

Noise Test Codes are standards specifying methods of measurement of noise emitted by various types of machines. Noise Test Codes are frequently used for checking compliance with noise limits.

ISO 3740 provides guidelines for preparing Noise Test Codes that prescribe methods for measuring the sound power levels of machines and equipment. Several factors influence the selection of the appropriate Basic Standard to be used. As examples of such factors the following can be mentioned: Size of source, character of noise, application of data and test environment.

Noise Test Codes must prescribe installation and operating conditions precisely. Development of Noise Test Codes requires a close collaboration between TC 43/SC 1 and the Technical Committees within ISO responsible for standardization related to the specific machine and equipment.

It is not possible within the compass of this paper to comment on all the Test Codes developed by ISO. It is necessary to refer interested readers to the publication under the reference paragraph.

STANDARDS OF CATEGORY 4

STANDARDS FOR MEASUREMENT OF NOISE EMITTED BY ROAD AND RAIL VEHICLES, VESSELS, AIRCRAFT AND OTHER MEANS OF TRANSPORT

These Standards can be divided into four groups relating to road vehicles, rail vehicles, vessels and aircraft, respectively. Each Standard specifies a method for measuring either the noise emitted by the noise source or the noise level inside the noise source. The operating conditions for the noise source during the test is also carefully prescribed.

Road vehicles

ISO 5128 (1st edition 1980): 'Acoustic measurement of noise inside motor vehicles.'

ISO 362 (2nd edition 1981): 'Measurement of noise emitted by accelerating road vehicles.'

ISO 5130 (1st edition 1982): 'Measurement of noise emitted by stationary road vehicles.'

DP 7188: 'Measurement of noise emitted by passenger cars under conditions representative of urban driving.'

Rail vehicles

ISO 3381 (1st edition 1976): 'Measurement of noise inside railbound vehicles.'

ISO 3095 (1st edition 1975): 'Measurement of noise emitted by railbound vehicles.'

Vessels

ISO 2923 (st edition 1975): 'Measurement of noise on board vessels.'

ISO 2922 (1st edition 1975): 'Measurement of noise emitted by vessels on inland water-ways and harbours.'

Aircraft

ISO 3891 (1st edition 1978): 'Procedure for describing aircraft noise heard on the ground.'

ISO 5129 (1st edition 1981): 'Measurement of noise inside aircraft.'

STANDARDS OF CATEGORY 5

STANDARDS ON MEASUREMENTS OF SOUND INSULATION AND SOUND ABSORPTION

This category of Standards includes at present three Standards: ISO 140, ISO 354 and ISO 717.

ISO 140 (1st edition of part 1-8: 1978. Part 9 is at present a

Draft Proposal). The title of this Standard is: 'Measurement of sound insulation in buildings and building elements.' It is a comprehensive Standard divided up into 9 parts.

ISO 354 (1st edition 1963 - 2nd edition is in preparation). The title of this Standard is: 'Measurement of absorption coefficient in a reverberation room.'

ISO 717 (1st edition 1982). The title of this Standard is: Rating of sound insulation in buildings and building elements.'

STANDARDS OF CATEGORY 6

VARIOUS OTHER NOISE STANDARDS

Category 6 includes standards which do not belong to the previous categories. The titles of a few of these standards are listed below.

DIS 4869 (1981). Measurement of sound attenuation of hearing protectors - Subjective method.

DP 7196. Method of describing sound at infrasonic frequencies with respect to its effect on human beings.

DP 7235. Measurement procedures for ducted silencers.

DP 7574. Statistical methods for verifying stated noise emission values of machinery and equipment.

DP 8201. Audible emergency evacuation signal.

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GOVERNMENT ACTIVITIES IN THE NETHERLANDS ON RESEARCH INTO HEALTH EFFECTS OF NOISE.

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Within the central government of the Netherlands 4 ministers have primary responsibility for the various parts of noise abatement. These are:

- the Minister of Defence and the Minister of Transport, who are responsible for carrying into effect the noise abatement policy for respectively military airfields and civil airports, under the Aviation Act (the Aviation Act of 1926 was therefore especially amended in 1978);
- the Minister of Housing, Physical Planning and Environment (VROM), who is responsible for the abatement of environmental noise from traffic and rail roads, industrial sites, appliances and foreign airbases, and residential noise etc., as well as for standards for aviation noise, under the Noise Abatement Act (which took effect in 1979);
- the Minister of Social Affairs and Employment, who is responsible for the abatement of occupational noise, under the Working Conditions Act (which partly took effect in 1983).

The Minister of VROM takes care of the coherence and consistency of all branches of the noise abatement policy.

FORMER RESEARCH PROGRAMS

To underpin the Aviation Act and the Noise Abatement Act, and the regulations drawn up under them, during 1973-1976 7 research programs were set up by the Interministerial Noise Abatement Committee (ICG), viz: Traffic Noise(27 projects), Rail Traffic Noise(14), Industrial Noise(18), Aircraft Noise(26), Machinery and Appliances(16), Residential Noise(16) and Special Topics(19). These programs now for the greater part are completed (English translations of the programs are available). At the moment 171 reports have been published, most of them in Dutch, with English, French and German summaries.

The research projects are aimed to underpin regulations. A part of the projects aimed at defining environmental noise limits, based on annoyance, speech intelligibility and sleep disturbance. These projects are reported in the following publications, which can be obtained through the Ministry of VROM:

Effects of noise abatement measures on residences along highway 16 at Dordrecht(VL-DR-14-01); Survey of residents'experience of noise abatement measures along National Road 10 in Amsterdam(VL-DR-14-02); Experience of sound proofing measures to reduce the effect of motorway noise in private houses(VL-HR-14-03); Study into the sensitivity of various areas and buildings to road traffic noise(VL-HR-16-01); Assessment of annoyance due to road traffic noise(VL-HR-17-01); Surveys of annoyance due to road traffic noise(VL-DR-17-02); The relation between speech intelligibility and traffic noise levels (VL-DR-17-03); Effect of ambient noise on the vocal output and the preferred listening level of conversational speech(VL-DR-18-01); Intelligibility of intervocalic consonants in noise(VL-DR-18-02); Preferred listening level for speech disturbed by fluctuating noise(VL-DR-18-03, in English); The effect of ambient noise on speech intelligibility in classrooms(VL-DR-18-04, in English); Effect of ambient noise on relaxed speaking and listening(VL-DR-18-05); Establishing maximum allowable values for 3 categories of noise-sensitive receptors other than houses(VL-HR-24-01); Disturbance of sleep by noise-(VL-DR-24-02); Speech reception threshold for sentences as a function of age and noise(VL-DR-24-03, in English); Noise nuisance in hospitals(VL-DR-24-05); Noise nuisance in homes for the elderly(VL-DR-24-06); Annoyance in schools due to traffic noise(VL-DR-24-07); Acoustic aspects in noise-sensitive receptors-(VL-DR-24-08); Effects of noise on a number of skills(VL-DR-24-09); Yardsticks and limits for noise from railways(RL-HR-03-01); Getting used to noise from a new railway line(RL-HR-03-02); Noise annoyance due to railroads(RL-HR-03-03); An inventory of vibration caused by factories, a questionnaire held among municipal authorities(IL-HR-05-01); Characterization and assessment of industrial noise-(IL-HR-09-01/02); Human response to whole-body vibration, a literature study(IL-HR-12-01); Residents'opinion on sound-proofing measures to reduce noise nuisance from aircrafts(LL-DR-14-01/02/03); Aircraft nuisance around military

airbases(LL-HR-16-01/02); Noise nuisance around general aviation airports(LL-HR-16-03/04); Report on a preliminary investigation into sensitivity to noise in mental hospitals(LL-HR-17-01); Noise annoyance in and around the house(WG-HR-01-01); Sound insulation and annoyance with respect to neighbour noise in renovated flats(WG-HR-14-01); The effect of loud music on the hearing of young listeners(BG-HR-07-01); Tentative evaluation of annoyance caused by shooting noise(BG-HR-10-01); Survey of spread of noise annoyance in the Netherlands(BG-HR-18-01);

RESEARCH PROGRAM ON OCCUPATIONAL NOISE

In aid of the Working Conditions Act the ICG-research programs have recently been extended with a research program for occupational noise, for which the Minister of Social Affairs and Employment is responsible. This program is divided into the following categories: Silent technology; State of technology; General applicable measures; Organizing Measures; Measures with respect to man; Approach from occupational health care; Noise measurement and assessment; Dose-response relations; Financial-economic consequences; Vibrations.

At the moment 18 research projects are being carried out; 4 of these refer to health effects, viz:

- Dose-effect-relations for annoyance (division of sound types and levels, determination of annoyance at these types and levels, investigation into psychic effects);
- Effects of noise-induced hearing loss on speech intelligibility (see the paper of G.P. Smoorenburg, team nr.2 , elsewhere in these proceedings);
- Inventory of the shock and vibration problem (inventory of foreign limits, survey of vibrations in various industries, population at risk);
- Effect of shock and vibrations on health (inventory of diagnostic parameters for health effects, investigation into complaints and drop out of vibration exposed workers, dose-effect-relations).

NEW RESEARCH PROGRAM ON ENVIRONMENTAL NOISE

As the greater part of the environmental noise regulations now have been accomplished, the objective of environmental research gradually had to be shifted from underpinning regulations to supporting the application. Consequently the number of research projects decreased. In view of these changed circumstances the 7 above mentioned ICG-programs for environmental noise are in a concluding stage. Running and new projects have been gathered in one new research program, for which the Minister of VROM is responsible. This program "Environmental Noise" is in coherence with the program "Occupational Noise". It is divided into the following categories: Health effects; Noise reduction at the source; Promotion of silent behaviour; Publicity and education; Outdoor sound propagation and insulation; Evaluation of regulations; Noise guarding; Financial-economic aspects.

The first 2 categories have a certain priority. For the coming period a yearly budget (for the total program) of 4 million guilders is foreseen(in 1980 for example for the 7 ICG-programs a total amount of 6 million guilders was spent).

The category "Health effects" principally covers the following topics: Medical effects of noise; Influence of noise on performance and behaviour; Noise annoyance; Sleep disturbance; Vibrations; Noise-induced hearing loss.
Depending on priority and budget research projects, according to these topics, can be initiated.

At the moment 6 projects are running, viz:

- Research on annoyance due to impulsive noise, a field survey(see the paper of R. de Jong, team nr.6, elsewhere in these proceedings);
- A laboratory research on annoyance due to impulsive noise (in connection with the above-mentioned survey);

- Annoyance due to noise from light rail vehicles (a survey among 600 persons in respect to noise from points, bends and intersections of streetcar-railways etc.).

- Annoyance due to noise from various sources (on the basis of surveys it is investigated whether cumulation of noise from traffic roads and other sources leads to masking, addition or synergism);
- Influence of replacement of Diesel-busses into Trolley-busses on annoyance (survey in a Dutch town before and after the replacement);
- Noise annoyance at recreation residences (survey on annoyance in non-permanent residences such as camping-sites and summer-houses).

Further it is intended to set up projects aimed at "dose-effect-relations for vibrations in residences due to industries and traffic roads" and "the influence of insulation measures and geography of the house on annoyance due to outside noises.

At the moment 3 projects are in a far advanced stage of preparation, viz: a) "Noise and health"; b) Noise, mental exertion and cardiovascular risk" c) "Noise and social behaviour". Project a) covers an extensive epidemiological research in terms of both physiological and psychosocial parameters. It will be combined with a laboratory research in which confounding factors, causality and generalizing of relations found in the field study can be further investigated.

Attention will be given to sensitive groups and the relation between annoyance and medical effects. Project b) is a laboratory research into the relation between noise exposure, task performance and mental exertion. Project c) is a literature study into the relation between noise and social behaviour, aimed at general conclusions based on theoretical concepts. English translations of these projects are available.

These 3 projects are in line with the wish of our Ministry to pay more attention to the influence of environmental noise on (non-auditive) physical and social aspects of health.

In the past our effort was primary aimed at noise annoyance, as this is generally the most important basis for developing environmental noise standards. Now that in the Netherlands the development of a system of environmental noise limits almost has been completed, our research effort also can be aimed at physical aspects of health. We are convinced that annoyance due to lasting, relatively high, environmental noise exposure is indissolubly connected to negative physiological effects, and therefore wish to contribute to research in this area. Happily the Dutch Parliament is also interested in these matters, so that, in spite of decreasing government expenses, financial possibilities still exist to initiate and finance some of this research. If more firm conclusions with respect to medical effects can be achieved, the results of research could be used:

- to test existing noise limits based on annoyance,
- to emphasize the need for noise abatement and, if necessary, to shift priorities,
- for information and publicity in order to support decisions for instance with respect to physical planning.

THE NOISE STANDARD OF THE U.S. OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION.

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Occupational noise is probably the most common health hazard in American industry. There are approximately 15 million people exposed to A-weighted, daily average noise levels above 80 dB. This figure includes noise exposed workers in the production industries, maritime, agriculture, mining, construction, and the military. About 5½ million of them are exposed to daily average levels of 85 dB and above in the production industries alone. These exposures take place in 300,000 individual workplaces. It is these workplaces that are now subject to the provisions of the Occupational Safety and Health Administration's (OSHA's) hearing conservation standard.

The free market system, so highly regarded in the U.S. today, does not function to protect workers against occupational hazards. Most consumers and stockholders are unaware of the fate of those who manufacture consumer products. Employers are not convinced that healthy environments promote productivity, and only rarely are workers able to reject a noisy, dirty

job in favor of a healthier environment with equal pay. In short, government intervention is necessary.

Worker compensation costs in the U.S. are rising steadily, but do not, as yet, compete significantly with the costs of noise control or hearing conservation programs. Recent estimates for hearing loss claims in the various states total about $13 million per year. Because the Federal Employee Compensation program is more generous than any of the state programs Federal employees collect about $30 million per year. Federal compensation costs are rising by about 10% to 30% per year.

Government regulators have been aware of the noise problem for some time, longer than for many other occupational health hazards. The first government noise standard in the U.S. was issued in 1969 under the authority of the Walsh-Healey Public Contracts Act and applied only to employers who contracted with the government. After the Occupational Safety and Health Act was passed in 1970 this same noise standard, often called the Walsh-Healey noise standard, became applicable to all employers engaged in interstate commerce. The Walsh-Healey (now OSHA) standard called for a maximum daily average sound level of 90 dB (A-weighted), with a 5-dB relationship between duration and level. This relationship has been called the doubling rate, the time-intensity tradeoff, and now the exchange rate, through the various stages of OSHA's history. The noise standard also limits exposures to continuous noise to 115 dB and impulse noise to 140 dB (peak sound pressure level). These levels had to be achieved by feasible engineering or administrative controls. Whenever such controls were infeasible

employers had to institute "continuing, effective hearing conservation programs." With the exception of the one-sentence hearing conservation requirement, the standard is still in effect today.

Because the standard lacks specificity in several places compliance has been very uneven. Many employers interpreted the requirement for continuing, effective hearing conservation programs as the issuance of hearing protectors and nothing more. In addition, the question of feasible engineering controls has been interpreted in a wide variety of ways, by the courts, by OSHA, and by employers. In an effort to improve the standard OSHA initiated the process of revision in 1972. The Agency followed the prescribed regulatory procedures, which included an advisory committee, a proposal published in the Federal Register, economic and environmental impact statements, public hearings, a "regulatory analysis", and a host of issue papers and other internal bureaucratic documents. An analysis of approximately 30,000 pages of testimony, comment, and technical material produced two major issues: the permissible exposure limit, whether it should be 85 or 90 dB with a 3 or 5 dB exchange rate; and the method of compliance, whether engineering control should remain the preferred method, or whether hearing protectors should be given equal status. These issues were the subjects of heated and protracted debate, and the OSHA hierarchy was unable to make a decision on either of them.

Finally in early 1980 the Agency made the decision to amend the noise standard for specific hearing conservation requirements and to leave the remainder unchanged. Thus the

90-dB permissible exposure limit, the 5-dB exchange rate, and the preference for engineering controls still stand. The final hearing conservation amendment, along with its supporting documentation, took about a year to prepare. It was published in the Federal Register on January 16, 1981.[1]

One of the required supporting documents was a "regulatory analysis" in which OSHA estimated the risks of not requiring hearing conservation measures and the costs involved in industry compliance. The Occupational Safety and Health Act directs OSHA to "set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity, even if such employee has regular exposure to the hazard dealt with by such a standard for the period of his working life."[2] Thus, Congress has given OSHA a rigorous protection criterion.

The Agency began the analysis by defining material impairment of hearing as an average hearing level greater than 25 dB at 1000, 2000, and 3000 Hz. OSHA had, in the past, used the American Medical Association's (AMA's) previous definition of hearing handicap, which was an average hearing level greater than 25 dB at 500, 1000, and 2000 Hz. However, the Agency rejected this definition, along with the new AMA definition of 25 dB at 500, 1000, 2000, and 3000 Hz. This was done on the grounds that hearing sensitivity at 500 Hz is largely irrelevant for speech discrimination and that the higher frequencies, such as 3000 Hz, become increasingly important as speech becomes less redundant and as the listening environment becomes

less favorable.

OSHA calculated the numbers of workers who would be prevented from developing material impairment of hearing if their employers complied with the provisions of the hearing conservation amendment.[3] The methodology incorporated age, sex, exposure level, and exposure duration parameters. The Agency also used three different "fences" or levels of hearing impairment so as to assess the degree of damage that would be prevented as well as the numbers of workers who would avoid material impairment. These estimates assume hearing protector attenuation of approximately 15 dB, backed up by a worker training and education program and audiometric monitoring. According to OSHA's methodology the following cases of hearing impairment will be prevented at "equilibrium", after all of the workers in the present system have retired and the only ones left are those who have been protected by the hearing conservation amendment:

Average Hearing Level Greater Than:	Number of Workers
15 dB	1,303,000
25 dB	898,000
40 dB	412,000

OSHA also estimated the number of workers who would benefit by not exceeding the 25-dB fence after various years of compliance with the amendment:

After 10 years	212,000 workers
After 20 years	477,000 workers
After 30 years	696,000 workers
After 40 years	799,000 workers
At equilibrium	898,000 workers

These estimates assume that hearing protectors will be worn by 100% of the workers exposed to average noise levels above 90 dB and by 100% of those workers exposed above 85 dB who have experienced noise-induced threshold shifts. As stated previously, an average attenuation of 15 dB is assumed. Because these assumptions may not reflect real world conditions, OSHA has estimated the number of workers protected using less optimistic assumptions:

Protector Use	Attenuation	Workers Protected
100%	15 dB	898,000
100%	10 dB	759,000
50%	10 dB	381,000

One can see that benefits of the regulation are greatly reduced with decreased degrees of compliance by employers and workers. Of course, OSHA's failure to enforce the amendment also could have negative results.

In addition to the benefits, OSHA also analyzed the costs of the amendment.[4] In the January 1981 version of the standard the Agency estimated the costs at $53 per year for each of the 5.1 million workers covered by the amendment. This comes to $270 million for the production industries. The costs per worker break down as follows:

Noise exposure monitoring	$14.82
Audiometric testing	$18.00
Hearing protectors	$ 9.53
Worker training and education	$ 8.47
Warning signs	$ .53
Record keeping	$ 1.59

In general, the costs per worker will be greater for small

companies, which will need to use consultants, and less for large companies with in-house programs.

At the time the hearing conservation amendment was promulgated it had been targeted by the Reagan transition team as a "midnight" standard because it came out so close to the end of the Democratic administration. One of the new administration's first actions was to postpone the effective date of the hearing conservation amendment. The effective date is the date on which a standard becomes enforceable. Some months later the American Federation of Labor sued OSHA for illegally delaying the amendment's effective date. After much discussion the White House allowed most of the provisions to go into effect,[5] while holding back a few issues for further deliberation. At this point the lawsuit was withdrawn. Finally, on March 5, 1983 the full standard became effective after some provisions had been modified and some had been revoked.[6] At this time OSHA estimated that the costs had been reduced to $210 million per year from the $270 originally estimated. This would amount to an average cost per worker of $41 per year. Part of the reduction is accounted for by a recalculation, which assumes that most employers will choose to rent noise measuring equipment rather than purchase it, and the rest is explained by the revocation of certain requirements. The extent to which the benefits also will be reduced is unknown. OSHA assumes that they will not.

Most of the changes between January of 1981 and March of 1983 reflect a shift from a specification to a performance approach. Most of the noise measurement requirements, such as

the instrumentation, methodology, and calibration requirements have been deleted, under the assumption that responsible employers will use acceptable measurement practices. Most of the audiometric test requirements remain, presumably because of the greater need for standardization. The following is a breif summary of the amendment's current requirements:

Employers must monitor at least once the noise exposures of all workers whose 8-hour average noise exposure levels are 85 dB or greater. Remonitoring is necessary with a change in equipment or work process that causes a significant increase in exposure level. All continuous, intermittent, and impulsive noise between the levels of 80 and 130 dB must be included in the exposure assessment. Area monitoring is permitted, but employers must use personal exposure monitoring when there is considerable variation of noise level over time. Workers must be allowed to observe the monitoring procedures and must be told about their exposures.

Employers must provide baseline audiograms within the first year of an employee's exposure to 85 dB and above, and annual audiograms thereafter. The tests must be conducted by trained and competent personnel and supervised by an audiologist or physician. Tests must be carried out in rooms that meet the 1969 ANSI criteria for background levels, and equipment must be calibrated according to specific schedules. Workers who experience significant (or in the final version "standard") threshold shifts are notified in writing, counselled as to the fitting and use of hearing protection, and referred to a specialist if necessary. A "standard" threshold shift is de-

fined as an average shift from baseline levels of 10 dB or more at 2000, 3000, and 4000 Hz.

Hearing protection must be worn by all workers exposed to 8-hour average levels of 90 dB and above. Employers must offer hearing protectors to workers exposed above 85 dB, and all must be given a variety of protectors from which to choose. Employers must provide protectors that are suitable for the specific noise environments in which they are to be worn. OSHA allows employers to use any of three methods for assessing the adequacy of hearing protector attenuation. The standard recommends using the Noise Reduction Rating (NRR), which nowadays appears on the protector package. To estimate the noise level under the protector the employer subtracts the NRR from the worker's C-weighted exposure level. If C-weighted levels are not available, 7 dB must be subtracted from the NRR to obtain the A-weighted sound level at the ear.

Training and education sessions must be given at least annually to workers exposed above 85 dB. These sessions must include information on the effects of noise on hearing, the purposes and procedures of audiometric tests, and the proper selection, fitting, use, and care of hearing protectors.

Lastly, employers need to keep records of noise measurements, audiograms, audiometer calibrations, and background levels in audiometric test rooms. These records must be given to employees or their representatives on request.

At this time it is difficult to know whether the amendment will be as effective as OSHA predicted. Field studies of hearing protectors show that the average attenuation is only about

one-third of the attenuation in the laboratory and the standard deviation is three times larger.[7] OSHA's attenuation assumption of 15 dB is probably at least 5 dB too high and a substantial portion of wearers receive less than 10 dB. The Agency's loose enforcement policies are not helping to conserve hearing, although these are subject to rapid reversal with a change in administration.

Undoubtedly, many American employers have recently initiated hearing conservation programs who would have delayed acting indefinitely, were it not for OSHA's promulgation of the final amendment. While the 1983 version is not as protective as the 1981 standard it is a significant improvement over pre-1981 conditions. While neither version will be as effective as controlling noise at the source, hearing conservation programs will be the best alternative, and in many cases the only method to protect workers until the feasibility question is decided, the American economy regains its health, and OSHA assumes a more vigorous enforcement policy.

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THE PROBLEM OF NOISE FROM THE POINT OF VIEW OF THE LEGISLATOR

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The bas.c Italian pronouncement on the subject of noise is sec. 659 of the Criminal Code, which imposes a penalty of up to three months' arrest or a fine of up to 120,000 lire on anyone who disturbs the occupations or repose of other persons by clamour, uproar or noise, by the abusive employment of sound-producing instruments or acoustic signals, or by inciting or not preventing the noise made by animals.

The limitations of this rule are manifest: industrial noise is completely ignored; road traffic noise is only taken into consideration with respect to the "abusive employment" (not further defined) of acoustic signals; the parameter to be applied is based on a concept that is subjective, and hence difficult to determine, namely the "disturbance" of occupations and repose. It is, in other words, totally insufficient.

The Civil Code has a section on emissions (sec. 844). In the case of noise, it lays down that the owner of a tenement cannot prevent the entry of noise, nor of other nuisances, from the tenement of his neighbour, provided they do not exceed the normal level of tolerability.

In addition to its very vague notion of "normal tole:ability", this rule has a very narrow sphere of application. Action can only be taken by the owner, and "in the application of this provision, the Court shall

strike a balance between the needs of production and property rights (paragraph 2). Turning to vehicular traffic, mention may be made of the provisions of the Road Traffic Act (Codified in Law No. 393 of 15 June 1959). Sections 46 & 47 lay down that vehicles with engines must be fitted with devices capable of reducing the noise they emit. Sections 112 & 113 forbid the production of offensive noises when driving, and state that silencers must always be kept in an efficient condition, and that acoustic signalling devices must always be used in a moderate manner, while their employment is forbidden in built-up areas except in cases of immediate danger.

The enabling regulations (Presidential Order No. 420 of 30 July 1959) contain two sections that establish the characteristics of acoustic devices and the ways in which their conformity with the law is to be determined (sec. 209-13), while secs. 214 & 215 define the sound levels permitted for engine noises and the way these are to be ascertained. These two sections have since been replaced by the more up-to-date ECC rules (brought into effect by Ministry of Transport orders in keeping with Law No. 942 of 1973), which impose a reduction in the sound levels permitted.

The provisions of the comprehensive enactment of health (approved by Royal Decree No. 1265 of 27 July 1934) can also be used against noise. Secs. 216 & 217 provide that operations injurious to health must be carried on away from dwelling places, or special precautionary measures must be taken on behalf of the neighbourhood. A list of insalubrious industries has been approved by the Ministry of health. As far as the modalities for the determination of noise are concerned, the Ministry has laid down certain general indications in its circular No. 162 of 27 September 1971: noise must be measured as the boundary of the factory, at ground level, and at a distance equivalent to the height of its wall; the suggssted limits are: 60 dB B by day and 40 dB A at night; a tolerance of 20 dB over the background noise is permitted, subject to a maxi-

mum of 45 dB A at night and 60 dB by day.

Another rule of interest for our present purposes is sec. 66 of the comprehensive public security enactment (approved by Royal Decree No. 773 of 18 June 1931), which lays down that noisy occupations and trades shall be suspended during the hours to be fixed by municipal by-laws and mayoral orders.

Turning to noise in buildings, Italy has no rules on soundproofing that apply to all types of dwellings. It merely has regulations for subsidised buildings and those undertaken by the State (hospitals, schools, etc.), for which circular No. 1769 of 30 April 1966 issued by the Ministry of Works lays down "standards for the evaluation and determination of the acoustic requirements of civil buildings".

It need hardly be said that current legislation in Italy concerning noise pollution in habitations and the external environment is both piecemeal and totally inadequate.

As to the workplace, there are, by contrast, a number of normative approaches, even in Italy: proposals of the Technical Commission of ENPI (National Accidents Prevention Board) on "Maximum noise exposure values in the workplace" (December 1979); proposal of the Confederation of Italian Industry on "Cheching of noise pollution in the workpl ce" (June 1980). Then, of course, there are the international provisions: ISO Recommendation 1999 "Assessment of occupational noise exposure for hearing conservation purposes" (1975); the OSHA (Occupational Safety and Health Administration, USA) rules; the ACGIH (American Conference Governmental Industrial Hygienist, USA) rules; the BOHS (British Occupational Hygiene Society) rules. It is worth pointing out that these rules are in fact applied, since they are written into the union agreements.

Other Italian rules of a more general nature can be found in sec. 2087 of the Civil Code, Presidential Orders No. 303 of 1956, No. 482 of 1975 and No. 547 of 1955, and secs. 9 & 19 of Law No. 300 of 1970 (orkers' Code), together with some proposals put forward by the Italian

Standardisation Board.

Moreover, account may be taken of the EEC's draft directive No. 2332 (Jan. 81) on "Protection of xorkers against the dangers of exposure to physical and biological agents at the workplace: NOISE". This is well advanced and it may be expected that regulations governing noise in the work environment may soon be uniform throughout the Community.

Noise due to air traffic is also the subject of Community directives whose elaboeation is at an advanced stage. An international set of rules already exists: ICAO (International Civil Aviation) regulations. The directives issued by the Italian Aircraft Register are much the same.

As we have seen, dwelling places and the external environment do not enjoy such extensive protection. The need to establish permitted noise exposure levels is particularly felt in Italy, since noise pollution in towns and cities is a cause for growing concern. The same can said with respect to the large percentage of the population exposed to this form of pollution.

In recent years, several studies and researches have been conducted on noise pollution in dwellings and the external environment in Milan, Turin, Florence, Rome, Pescara, L'Aquila, Bari, Palermo and Catania. These have revealed the presence of noise values from which it is clear that somewhat alarming levels of noise pollution afflict wide strata of the population at various times during the day, with various adverse effects on their health.

The noise levels observed in these numerous investigations show that on many occasions the maximum permitted limits envisaged by the laws of other countries, or established by international bodies (WHO, EEC, OECD), are being exceeded. A similar picture emerges from research work conducted in places of work.

For these reasons, a provision reflecting the awareness of the legislator of the question of noise pollution has been inserted by the draughtsman into the enactment establishing the Italian national health

service (Law No. 833 of 23 December 1978). This is section 4, which requires the establishment and periodic review of "the maximum exposure limits for noise emissions in work and dwelling environments, and the environment at large".

With a view to the practical application of this section, the Ministry of Health has initiated a national and international cognitive investigation designed to achieve a better definition and unterstanding of the [illegible] aspects of the question.

In this connection, it is worth emphasising that, in the EEC, noise, [illegible] a first-category pollutant in its environment programmes, has [illegible] been dealth with in particular instances relating to the [illegible] noise pollution emanating from specific types of machinery and [illegible].

[illegible] subsequent step, the Superior Health Council, at the request of the Ministry of Health, has formed a working party for a closer interdisciplinary examination of the question of noise pollution. This group has been completed by the inclusion of experts from the administrative bodies concerned, university departments and other bodies and organisations having jurisdiction over the subject, so as to ensure that the hygiene, health, technical, juridical and administrative aspects of the question are fully covered.

The working party's terms of reference have been initially restricted to the examination of questions relating to noise pollution in habitations and the external environment. These, as we have seen, are sectors for which the existing law is virtually devoid of provisions. They are thus a priority for the establishment of an appropriate legislative coverage.

The working party has examined the available technical literature and legislation of other countries, together with the opinions expressed at the OECD Conference on Noise, held in Paris in May 1980.

Account has also been taken of the EEC studies and directives. As already stated, the latter are solely concerned with specific machinery

and products (exhaust devices for engine-powered vehicles, wheeled agricultural and forestry tractors, and motor-cycles, construction site machines and materials, etc.).

Attention has also been paid to Italian studies, proposals and findings published, for example, by the Superior Health Council, the CNEN (National Nuclear Energy Commission), the Municipality of Rome, and the Confederation of Italian Industry.

Lastly, feasibility of application has been borne in mind, apart, of course, from the basic hygiene and health aspects of the subject. Care has been taken not to recommend sound emission acceptability limits that could not in fact be enforced as matters now stand in Italy, even though they are recommended by the OECD and already in force in several countries.

An out line Order approved by the Superior Health Council has been redrafted and modified in the light of information and comments emerging from meetings with the manufacturing organisations primarily involved. The final result has been the preparation of a draft Order composed of eight sections, plus a schedule containing all the technical regulations.

However, in the light of the considerable innovative aspects associated with the question of noise pollution in dwellings and the external environment - a subject, as I have had occasion to remark - that is currently devoid of a complete, organic legislative coverage, and prior to the final submission of the proposed Order to the National Health Council in accordance with the provisions of sec. 4 of Law No. 833, it has been though desirable to submit the said proposal to the government offices primarily involved in the question of noise pollution for their observations and comments.

In the light of such observations, it is expected that during the course of the next legislature:

- an outline law governing matters relating to noise pollution will be passed;
- an Order will be promulgated designed solely to establish the maximum sound exposure limits in dwellings and the external environment.

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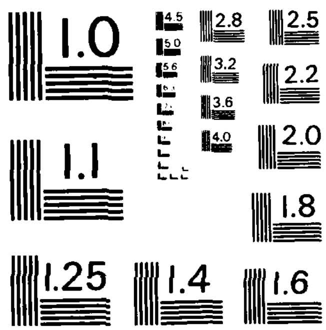

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NOISE POLLUTION: THE PRESENT POSITION

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Before addressing this congress, which has been summoned to publicise the research work and studies carried out, and discuss at a high scientific level the problems associated with the serious effects of noise pollution on all members of society, I consider it both a duty and a pleasure to convey to all those present the greetings of the Minister of Labour and Social Welfare, Signor Scotti, who has asked me to formulate on his behalf the hope that your work will be proficuous and your congress a complete success.

To these good wishes I wish to add my own words of appreciation to the organisers, both for the impressive and extensive participation of eminent research workers, and for the sensible way the work of the meeting has been divided into study groups, so that specific questions connected with noise can be examined independently. A particularly cordial greeting to Prof. Rossi, the animator and promoter of the Congress.

My paper, too, is intended as evidence of my affection for subjects bearing on the topic of "safety at work", an affection rooted in both my earlier experience as a director of factory inspectorates, always entrusted with a decisive role in the prevention of accidents and occu-

pational diseases, and in the work of supervision, and also in my capacity as a lecturer at the University of Rome.

Noise is a danger inherent in all forms of human activity. Constructive discussion may thus be called upon to provide useful contributions to the study of noise, including the initiatives to be pursued at the several national and Community decision-making levels.

Noise is a matter of great topical interest. It represents a high potential source of danger to all persons exposed to it. In this respect, its effects are felt by both workers and ordinary persons without distinction.

Nor can we underestimate the technical difficulties associated with its containment for the purposes of prevention, especially when an appropriate, organic legislative coverage of the subject is lacking.

Noise has gradually acquired particular importance in step with the growth of our technology-dominated society, of which it is the constant, albeit unwelcome companion.

Rapid, tempestuous industrialisation in Italy, particularly since the war, has quickly raised the standard of living of the population. At the same time, however, it has brought about a decisive and massive increase in occupational and allied diseases caused by noise.

Objective assessment of the situation readily shows that the absence of precise prevention regulations has been one of the prime causes of this development.

A turning-point with respect to this and other subjects in the field of prevention has certainly been reached through the gradually increasing awareness displayed by employers, workers and their organisations, and public opinion itself, with its growing sensitivity to matters relating to environmental safety.

The ensuing discussions have elevated questions of life and work environment safety problems to issues of great moment on the national level. They have also underlain the passing of the Health Reform Act

which, in theory at any rate, has introduced a new philosophy and a new strategy with regard prevention.

In the system delineated by the national health service in Italy, Law No. 833 primarily approaches the complex subject of prevention as a matter associated with work accidents and occupational diseases. Stress is laid on both ambient and collection prevention, these being the sectors in which the Italian legislative provisions were hitherto most glaringly and notoriously defective. Of major significance, inter alia, is the provision whereby the State is entrusted with the task of certifying the safety of machines, plants and individual means of protection.

We are here concerned with a typical primary prevention institution aimed at effectuating, for the first time in Italy, steps that are preventive in their conception, and not merely forms of correction or repression.

It is clear that certification *qua* institution will be in a position to make a decisive contribution to reducing the noisiness of machinery, tools, etc. before they are built, distributed and employed in manufacturing operations. Considerable technical difficulties certainly stand in the way when radical solutions are sought, especially when the possibility of totally suppressing the noise made by certain machines is raised. Even so, solutions whose ǒriginality and technical and technological way-aheadness are such that the safety objectives envisaged by the legislation are attained cannot be ruled out a priori.

Law No. 833 also deals with an equally interesting point from the prevention angle, namely the detection, ascertainment and cheching of danger factors in living and work environments through the enforcement of maximum acceptable concentration (MAC) levels and maximum exposure limits (TLV) for chemical, physical and biological pollutants and sound emissions in work and habitation environments, and in the external environment. A first encouraging application of the principle in sec. 4 of the Act occurred last month, when these limits were laid down for ex-

ternal ambient air pollutants. What is important is that this form of secondary legislation is open to rapid updating or adaptation.

The planning associated with the Act also envisaged the enactment of a comprehensive measure on safety. This would have rearranged and updated the current legislation on labour and manufacturing with a view to preventing accidents and occupational diseases, so as to ensure the health and physical integrity of workers.

The power delegated in section 24 expired some time ago. The government has thus lost the opportunity of passing a measure that should and could have filled in all the main lacunae of regulations going back almost 30 years. All the previous legislation, therefore, remains in force. In particular, as far as noise is concerned, the main source is still Presidential Order No. 303 of 19.3.1956 (once again sec. 24), which requires the adoption of measures recommended by the state of the art in the case of operations resulting in shaking, vibration and noise injurious to workers.

The general terms in which this section is framed, however, has so far made its exact and complete application very difficult in the absence of reliable reference parameters.

Enforcement of the provisions of this section was primarily entrusted to the "rule-making" power (see sec. 10 of No. 520/1955) of the inspectorate of factories prior to the transfer of jurisdiction to the new local structures.

Through the exercise of this power, supervisory bodies could resort to the section in the detailed definition of measures most appropriate to a concrete situation. This special power, however, has been conferred by Law No. 833 on the local health unit officials responsible for work safety. The position is likely to get worse, therefore, since reliance cannot always be placed on the alternative offered by the last paragraph of section 20, which states that measures for which no specific provision is made must be carried out jointly by union representatives and the

employer in accordance with the modalities established by collective labour contracts and similar agreements.

Another section of the 1956 Order - namely section 48 - is also used. This relates to the notification of new plants. It can be made the occasion for marked improvements in working conditions as far as noise is concerned, since they can be prescribed at the design stage. It is obviously easier to introduce health and hygiene improvements before a plant is installed than when it is engaged in industrial production.

Despite the precarious times that now prevail, the Ministry of Labour is continuing to work out safety regulations as a contribution to better understanding of the occupational hazards associated with manufacturing. Suffice it to mention its numerous circulars and directives on the prevention of specific risks in the building trade and the handling of chemical substances, etc., together with the many initiatives undertaken by the EEC.

The preliminary examination of ministry is now undertaking of the proposed Community directive on the protection of workers against the dangers of noise forms part of this approach. The proposal itself represents a first, decisive step forward with respect to the defective Italian legislation, since the aim is to incorporate and innovate the specific subject-matter with a view to giving rise to a single legislative text comprising prevention under the several technical, medical and organisational aspects of the adverse effects of noise at work.

During these *travaux préparatoires*, various comments were been made to improve certain aspects of the text that were felt to be not entirely satisfactory. The proposal was then reworked, though it must be admitted that the new version is primarily founded on the contents of the first. It may also be remarked that substantial agreement has been reached between government, employers and the unions on the noise tolerability limit in the workplace, namely 85 dbA, with on exchange rate of 3.

I may add, too, that in the case of insurance against accidents and

occupational diseases the Ministry of Labour has worked out the draft of a Bill delegating powers for the revision of the comprehensive text of 1965. This reform includes the introduction of a mixed list in accordance with the Community directives. This will allow for the possibility of recognising even a non-listed occupational disease when irrefutable proof of its occupational origin is forthcoming.

In conclusion, one may express the hope that the proposed directive, intended as it is to bring uniformity on the European scale in a sector with such vast implications, may soon be implemented in a manner whereby operators are presented with a modern, strict set of regulations capable of combating one of the most serious risks of our times as far as both workers and all members of society are concerned.

Nor should one underestimate the juridical weapon offered to the government by sec. 4 of Law No. 833, dealing with MACs, since there are no longer any barriers to its implementation, other than those of a technical kind, themselves mainly ascribable to the objective difficulties that undoubtedly exist in this field. In the same way, due weight must be attributed to a desirable organic enactment covering certification.

Moreover, at this particular time, while several political parties have put forward requests for the undoubtedly necessary revision of Law No. 833, it is not proper to overstress its many insufficiences and gaps, and its numerous failures to do what was expected of it, bearing in mind that implementation of its most lofty objectives in terms of prevention must inevitably be gradual.

In my opinion, therefore, we must persevere along the main highway of prevention traced out by the Act establishing the national health service.

By the same token, this must not be draped in the myth of untouchability on any occasion when its refurbishing, perfection or correction proves either necessary or opportune in the general interest.

NOISE-INDUCED HEARING LOSS AND SOCIAL INSURANCE PROTECTION: EXPERIENCES AND PROSPECTS

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INTRODUCTION

Because of the technological development, noise became the spreadest risk factor and the one which the largest workers number is exposed to (1,25).

We admit the otodamaging activity of industrial noise, or anyway of the working one, can be strengthened, directly or indirectly, by the living sorrounding sound contamination.

In fact the civil and urban noise looks able:a) to increase the acoustic total charge, expressed in sound continuous equivalent level (Leq)(24); b) to keep the workers from taking advantage, during the sixteen hours elapsing between the different duties, of the "effective quiet" period necessary for the complete reinstatement of the auditory sensitivity, temporarily reduced (TTS) during the eight working hours (3,9,11,39).

In parallel with these considerations, and particularly referring to our country, the noise-induced hearing loss (NIHL) seems to be the most frequently diagnosed occupational disease and the one responsible for the highest number of life - long pensions due to permanent disability.

STATISTICAL DATA

The NIHL cases compensated in Italy are 91.281, according to the data given by INAIL Mechanization and Statistical-Actuarial Services, and they represent the 40,3% of the life-long pensions settled for all the occupational diseases.

In Western Germany, where the NIHL is insurance protected, independently of the kind of work responsible for, the compensated cases, since the insurance protection beginning up to the whole 1980, are a little more than 19.000 (40). In France, where on the contrary the insurance protection is limited, just as in Italy and in Great Britain, to a few kinds of noisy recognized works, less than 2.923 cases have been allowed to be compensated within the 1968-1977 period (8).

In Italy the NIHL compensated workers have been 1.375 during the 1953-1962 period, more than 46.000 during the 1977-1978 period and 12.233 in 1979.

Such a dizzy increase can be chiefly ascribed to the 1977 minimum compensation lowering from 21% down to 11% (25).

Anyway, the NIHL life-long pensions number increased also in other countries; for instance, in the Canadian District of Ontario, the compensated cases result to be 39 in the 1956-1960 quinquennium and 5.755 in the 1976-1980 one (1).

The 25% of the compensated Italian subjects in the 1953-1962 period were from 56 to 73 years old (18); according to more recent data the starting age class distribution points out that almost the 58% of people receiving a NIHL life-long pension are older than 45 years.

Still referring to our country, the percentage disability at the moment of life-long pension settlement, which was on an average of 26% in the 1953-1962 period (18), is actually approaching to 11%.

All these data seem to confirm that: a) the NIHL, just likewise other occupational diseases as silicosis, comes out or, anyway, is prevailingly denounced during the second half of the life (22); b) the industrial noise, at the different ages, can advance and accentuate, up to an indemnifiable percentage (7), the reduced auditory sensitivity connected to the presbycusis in its widest meaning (2) and as "hearing loss mainly for high tones due to advancing age" (5).

HEARING LOSS PERCENTAGE DISABILITY ASSESSMENT INCONGRUITIES

In Italy we can freely choose methods and criterions to check the auditory sensitivity level, to measure the global hearing loss and to translate it to percentage disability (24;29;32).

After the minimum compensation lowering, and whereas during the assessment we employ a kind of method that privilege the little threshold shifts, it's possible to settle a permanent partial disability life-long pension to workers with a pure-tone audiometry down to the standard lower limit, which aren't yet qualifiable as having a hearing loss, according to the criterions pointed out by some authors and international institutions (32).

The different methods emploied in our country can attribute a percentage disability from a little more than 0 to 15% to a subject with a hearing loss of 25 dB on 500, 1000, 2000 and 3000 Hz and of 45 dB on 4000 Hz. In fact, the disability can be differently valued even basing on the same audiogram.

Waiting for all these problems to be re-examined according to the EEC directives, we consider as absolutely necessary to adopt a uniform and more equitable methodology, in agreement with the social forces. One of the problems to agree upon is the reduced auditory sensitivity levels and characte-

ristics to be related to: a) the hearing loss beginning; b) the indemnifiable hearing loss threshold (11%).

About this question, we have to remind that AAOO distinguishes (33) between "hearing impairment", i.e. any permanent hearing alteration, "hearing handicap", which is an impairment sufficient to affect one's efficiency in everyday life, and "hearing disability", that means inability to remain employed at fullwages, and we have also to remind that 25 dB hearing losses on 500,1000,2000 and 3000 Hz still make audiogram valued as a normal one (27).

We also want to emphasize that the article n.74 of the law in force (DPR n. 1124 of June 30th, 1965) defines as permanent partial disability the one which endangers partially, but "in an essential way" and for the lifetime the "attitudine" to work.

NOISE-INDUCED HEARING LOSS PARTICULAR CHARACTERISTICS

The NIHL is a partial deafness, usually bilateral and symmetrical (14,37). Its audiometrical outline still has to be precised (10) and it represents a some way particular kind of occupational disease. It involves, in fact, a particulary quantitative aggravating alteration (32) of a previous auditory condition, which is already declining, because of the advancing age. Therefore, it's just from the quantitative point of view that we can define the NIHL as a hearing loss higher than expected according to the age and presumably ascribable to the working noise, that's to say "estimated noise-induced permanent threshold shift", or "age corrected hearing loss" (4,5,16,35) with some aspects of "premature presbycusis"(7). The irreversibility after TTS disappeared and the fact that it isn't spontaneously evolutionary after the noisy work abandonment are among its essential characteristics

(12,35,38).

Besides, the NIHL doesn't look such to jeopardize the "working ability" (12) or, anyway, it doesn't seriously endanger the work course in a noisy surrounding (36).

Briefly, we mean that its influence is especially in the social field (37) and on the life quality, if of course it exceeds a certain threshold involving the speech classical frequences (19,32).

In the past hearing loss affected people were co[illegible]lered as particularly suitable to start and/or continue to [illegible]rk in noisy places. At present, moral reasons, according w[illegible] [illegible]odern medicine preventive trend, advise against these subjects employment, or further employment, with the intention of saving their residual hearing (30,35).

FORENSIC MEDICINE PROBLEMS

All these new situations present different doctrinaire and practical problems, among other things concerning:

- the relations between auditory function and "attitudine" to work and between the deficit revealed by the pure-tone audiometry (ATL) and the handicap resulting from other analysis or from the questionnaire, and the importance to be given to the different frequences relating to their usefulness to discriminate the words and the noises (19,29,32);
- the eventual resort, during the measurement, to a presbycusis correcting factor, which isn't admitted by everybody (17), but which is considered admissible especially when the deficit on 4000 Hz (14) is valued important: in the case of 60 years old workers the hearing loss could depend upon the age for something less than 50% (6);
- the criterions to be followed when re-examining, on the basis of a denounced aggravation, ex-workers and subjects

which already abandoned years before a noisy activity listed on the table, or even out of it. Apart from any other consideration, from a general point of view, even the simple existence of an aggravation could give birth to doubts: since the audiometrical threshold, through repeated controls doesn't correspond to a point, but to a class, a sure aggravation should be admissible only when finding a 25 dB swerving on at least one of the considered frequences (34); we could say that "an apparent improvement is observed almost as often as a loss" (4);

- how and when carry out the audiological study, preferably without limiting it to the ATL (27,29,33) and the criterions to be applied for the diagnosis and the valuation of the subjects exposed to NIHL and carriers of otological diseases responsible for sensorineural loss;
- the possibility to allow a hearing aid, however useful when the speech classical frequences are endangered (31), and the opportunity, or not, to consider, when valuating, the eventual improvement that it will involve: in INAIL sector of the actual insurance system the indemnity tends to compensate, of the damage connected with the professional diseases, the disability, coming from the "attitudine" to work damage, meaning the biological earning ability, and this kind of disability could result unmodified by the hearing aid concession.

In the NIHL case the compensation seems to concern a larger area than the traditional one (26). Moreover, also in the international field, compensation boards generally do not compensate each loss of hearing, but only the one involving the understanding of speech, which may therefore be called social hearing impairment (35); hearing primary function is to ena-

ble the interpersonal relations based on speech understanding in the usual living conditions (15,32,33). There are also other problems, which, anyway, cannot find any innovating solutions in the actual laws frame.

INSURANCE PROBLEMS

The NIHL insurance protection (DPR n.482 of June 9th, 1975/item n.44 of the enclosed table n.4) considers 22 kinds of works, listed letter by letter from A to Z, which are valuated noisy and otodamaging.

The 1962 EEC list, on the contrary, proposes the NIHL protections independently of the kind of work.

The 44th item is lacking of "constitutional completeness", which is typical of any kind of list or table system, but allows to apply the "cause presumption" criterion, which is favourable for the workers: a hearing loss, presenting a NIHL diagnosis compatible audiogram, checked out in a tinker, is considered as an occupational disease, without beeing necessary a risk existence actual control.

The EEC proposed item, on the contrary, presents the disadvantage to request to give documentary evidence, case by case, of the real and not episodical exposure to otodamaging sound levels. The refore it can be difficult to employ it: a) because of the difficulty to define, from the conceptual point of view, for all the NIHL and exposure kinds, "risk criterions" universally accepted; b) because of the difficulty when applying them, to precise, time by time, the amount absorbed by the examined subject. It's well known, in fact, that a given sound level is not synonimous of damaging exposure (17), that the equal energy principle (5) doesn't consider either the acoustic charge temporary distribution or the audi

tory effort recoveries allowed by quiet pauses (28), and that it doesn't seem to exist any strict relation between "amount" and hearing loss (17), maybe and partially because of the limits ascribable to the measurements methods (20), and of other damaging factors co-existence (23).

In fact, the sectorial global protection system effectable by the EEC item, which seems to emphasize the disease identification rather the risk, is subordinated to a valuation on the borne acoustic charge (25,26). The NIHL can be distinguished from different aetiology analogous sensorineural hearing losses only in the starting phase (21), when it isn't yet felt and denounced. Therefore the diagnosis is usually formulated by exclusion and basing on the working anamnesis. In reality, the otologist task could be made easier by a specialistic and audiometrical tests dossier, subject by subject, such to give information both on their basic conditions and on their alteration during the working years (17,25,26).

IURE CONDENDO PROSPECTS

In order to avoid protection lacks, it has been suggested the opportuneness to complete the 44th item works list with the reference to any other activity such to expose to noise of sound continuous equivalent level, equal or higher than a given threshold value.

The Patronage's Institutions seem to prefer the addition to the table list of a W: "other works however exposing to the noise risk"; this is the formula suggested during the Industrial Medicine Congress, which took place in Sorrento in 1982.

In the frame of a whole sector more adequate order, an

agreement could, maybe, be obtained on a new proposal, like, for instance, to complete the 44th item list (eventually better structured and amplified like INAIL Occupational Risks Aecertainement Technical Consultation Service suggested) by the reference to other works such to involve certainly otodamaging exposures. The chosen formula could be completed by an explicative note at the foot of the list, like the one proposed to revise the table enclosed to the OIL convention n.121 "for the application the level and the kind of the exposure shall be considered" (13).

PREVENTION ALLOWS A BETTER PROTECTION

The "exposure limits" suggested for the noise seem to "accept" danger coefficients higher than the ones admitted for any other pathogenic factor: in fact, only unrealistic levels could guarantee the Corti organ integrity or, atleast, avoid any handicap to the tender eared subjects (8%, or something more, of the population), which unfortunately are unidentifiable before beeing started off on the work (30,32,33, 35). We can therefore consider as justified the definition "risk criterions", and the individual recourse to technical and medical prevention integrative intervention proves to be necessary (16).

These interventions can result particularly effective when compulsory (16); among the other things we remind: a) the audiometrical controls effected during the first working years (32,33) allow to identify the tender eared subjects, to be switched to quiet activities before any important loss can settle; b) analogous periodical controls on the remaining working population allow to identify the subjects which reached the maximum tolerable loss with regard to their

age and which are in their turn to be transferred to a quiet department, in order to avoid a sure social handicap at the pension time (30,35), when the presbycusis complex damage is growing and becomes evident (2,32).

A NIHL more complete insurance protection will probably be effected just if we realize in all working places the technical prevention, which requires continuous sound level measurements, and the medical prevention, which requires periodical audiometrical controls (26), the results of both having to be registered on special individual and risk sanitary booklets.

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CONCLUSIONS FOR FUTURE WORK

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This Congress on Noise as a Public Health Problem is a special one, as those of you who attended our previous congresses know and those who attend it for the first time will quickly find out. The International Commission on Biological Effects of Noise (ICBEN), who sponsors the congresses, was formed to bring about closer international information exchange, research collaboration, and cooperation in the development of practical noise criteria and protection methods. The commission fosters international collaboration in research through its eight noise research teams, who are in continuous contact during the five years between our congresses. However, advancing and reviewing scientific progress has not been the only goal of the commission. It has also tried to provide information in a usable form to international organizations and governments, who are required to originate and implement practical noise control programs. This effort should lead to a quieter or - pessimistically expressed - not much noisier future. The informal contact with politicians, government administrators, and international

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organizations is maintained by the individual commission members and is intensified and reactivated at our congresses. This interaction should be, and hopefully is, a two-way street. First, it can provide researchers and team members with a perspective on policy decisions and legal requirements for protecting people against noise; consequently, they see the need for specific research solutions. Second, the administrators and politicians gain an up-to-date status report on research accomplishments and recommendations for future research that should be supported. Therefore, it is more than appropriate that this first session of the congress was devoted not to Noise as a Public Health Problem but to Noise as an International Public Health Problem.

It was gratifying to hear in this session about the activities and action programs of the various international organizations and commissions. We heard about policy decisions and about ongoing as well as planned research programs. Obviously, despite the fact that in many countries fiscal austerity overshadowed environmental progress, several organizations and countries have made considerable progress since our Freiburg meeting five years ago. The World Health Organization's ambitious and extensive program on health aspects of urban noise including practically all of our earlier recommendations on this topic is an example of outstanding international collaboration and coordination and deserves full support from all quarters to assure its execution. The criteria document on noise by WHO (1) presents an up-to-date and well balanced status report of our current knowledge of the effects of noise on people. It is, of course, available for international dissemination and use. The Commission of European

collaboration between users and producers of the international standards.

The conclusions and recommendations of the Freiburg congress five years ago highlighted three research areas deserving international emphasis:

1. The long-term general health effects of living in noisy environments with particular emphasis on noise as a potential risk factor in the development of cardiovascular disease.

2. Sleep research and research on the psychological and physiological effects of noise conducted in the field; i.e., in the real-life environment.

3. Hazard assessment of interrupted and impulse noise.

These priorities were well reflected in the national and international research programs presented in this session and particularly those by WHO and CEC. Furthermore, it is gratifying that with respect to the third problem, impulse noise, international agreement has been obtained on how impulse noise should be measured and rated with respect to hearing impairment. It is also hoped that, despite the need for continuing research, the new standard will now be used by governments and organizations to assess and regulate impulse noise hazard. In the other two areas extensive research programs have been formulated and preliminary results will be presented in the team sessions which follow. It is probably still too early to expect in these two areas authoritative, scientific guidance for operational application, on which all of us could agree. However, agreement has undoubtedly been obtained in some of these areas on research methods, approaches and standardization which may open the way for later consensus on assessment of effects and subsequent criteria.

Obviously, our primary goal in the coming years must be to support the efforts presented in this session and planned and started by the various organizations. These efforts must be supported by ICBEN as an organization as well as by its individual members. We must support the programs and their goals in general as well as their individual projects. Furthermore, we must encourage research in new areas. In some of the programs just reviewed the potential synergistic effects of noise and vibration were mentioned. It is important to stress the close relationship of these two areas, not only with respect to their action on people but also with respect to their origin and abatement. This is particularly true in buildings. Although international standards are available on vibration, as they act on people in buildings or transportation vehicles[8] or through the use of hand tools[9], guidelines on the combined vibration plus noise environment are missing with respect to health, annoyance, and comfort. Vibration should certainly be considered when we conduct studies on the effects of noise on health and on the response of the community.

In summary, it appears that the dialogue and collaboration between our noise teams and the various international organizations and governments were effective and productive. I hope that through the discussions at this meeting it will become clearer to the researchers what is expected from them and clearer to the users what science can realistically provide in the foreseeable future. Working together, we should be successful in obtaining continuing support for our programs and in arriving at objective, scientifically, well-founded standards to be used as tools in national and international efforts to control noise.

Communities was successful in organizing and prioritizing collaborative efforts in the sleep disturbance and community response areas with scientists from various countries participating. Several reports at this congress came about because of these efforts. The OECD countries have made significant efforts in the past five years to harmonize the comprehensive policies adopted by the individual governments. The 1980 OECD Conference on Noise Abatement Policies(2) reflects this positive effort and documents a realistic assessment of the international situation.

In between the policies, programs and actions of the governments on the one side and the research results of the individual scientists on the other is the extremely important work of the national and international technical standards organizations. We heard the overview of the extensive work of the International Standards Organization's (ISO's) Technical Committee TC43 on Acoustics and its subcommittee on Noise, which is primarily responsible for work of interest to this congress. In many instances the recommendations of our earlier congresses have been adopted in the work of ISO and IEC (International Electrotechnical Commission). The ISO/DIS 7029 on "Threshold of Hearing by Air conduction as a Function of Age and Sex of Otologically Normal Persons"(3) as well as the revision of ISO 1999 "Assessment of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment"(4) reached the essential consensus state in the last five years and can now form the basis for more uniform international prediction and assessment of noise-induced hearing loss. The A-weighted equivalent continuous sound pressure level was accepted for the time being as the most meaningful indicator for the prediction and prevention of hearing impairment caused by

noise exposure. This measure has also been accepted by most researchers and countries for the prediction of the effects of non-steady state noise and impulse noise as long as the unweighted instantaneous peak sound pressure level of these noises does not exceed 145 dB at the ear(4)(5). For most industrial and other practical applications the latter precaution is no serious restriction. All scientists will not be completely satisfied with the compromises of these and other standards. Some new proposals and opinions, based on newly acquired data on the description and rating of impulsive noise, will be presented at this congress. However, there are other presentations which support the L_{eq} approach taken in the standard. The standard adopted L_{eq} for the assessment of the effects of impulse noise not just for convenience, but also because it does not appear to overestimate or underestimate most noises, it seems the best compromise at the present time(5)(6). Probably, five years or more would be required to reach agreement if new data presented at this congress would be considered convincing evidence to update or change our position. The standards on the assessment of community noise(7) and on occupational noise exposure provided the much needed basis for the specifications of a standard by IEC on integrating sound level meters. Hopefully, a standard on personal dosimeters based on the same agreements will soon follow. One conclusion of the Freiburg meeting was that use of such standardized instruments was urgently needed to obtain reliable and comparable data on long-term, general health effects, sleep research and impulse noise. The presentations by the International Labor Office (ILO) and CEC today pointed out both the need for the application of these standards and for the harmonious

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ICBEN Team Working Sessions

Team No. 1
Noise-Induced Hearing Loss

Chairman: W.D. Ward (U.S.A.)
CoChairman: H.-G. Dieroff (East Germany)

Invited Papers on Specific Topics

NOISE-INDUCED HEARING LOSS: RESEARCH SINCE 1978

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Three or five? I refer in this case not to dBA, but to years, and not to years of noise exposure but the time constant in the exponential growth of the number of papers dealing with the relation between noise exposure and damage to hearing, both temporary and permanent, in man and in experimental animals. My impression is that it has about doubled at each of our successive Congresses, so "five" apparently wins this particular battle. But alas, the amount of time and space allotted for my review remains constant, so the scope must be restricted even more stringently than at Freiburg. Accordingly, the two main topics to be considered are (1) progress toward determination of the empirical relations between exposure and permanent damage, mostly in animals, and (2) developments in the prediction and manipulation of individual susceptibility to damage as manifested by studies of both temporary and permanent changes.

Measurement of Damage

One of the main questions that has generated considerable research in the last decade is: "Noise damage: do we measure it correctly?" Although most studies of humans have long assumed that the elevation of auditory threshold for pure tones is the most appropriate indicator of damage, the lack of agreement between permanent threshold shifts and structural damage to the cochlea in experimental animals (e.g., Lim et al., 1982; Stebbins et al., 1979; Ward and Turner, 1982) has led to efforts to find auditory capabilities that may more accurately reflect the state of the cochlea, and perhaps, therefore, better predict the ability to understand speech. Because animals with scattered damage, in the form of destroyed hair cells (HCs) may have fairly normal thresholds, considerable human research has been devoted to study, in persons with high-frequency threshold losses that are probably noise-induced, of such characteristics as difference limens for intensity and frequency, critical bandwidth, tuning-curve shape, temporal integration, and tone decay, at low frequencies that appear to be normal in sensitivity (e.g. Wightman, 1982). However, there is as yet no convincing evidence that any of these measures is more sensitive to "latent" damage than the pure-tone threshold; i.e., although

abnormal difference limens and tuning curves may be found, they occur only when some PTS has also occurred. A typical report is that by Tyler et al. (1982). Indeed, they may be less sensitive; for example, Syka and Popelar (1980) found temporal integration to be quite unaffected by exposures that produced 20 to 30 dB of PTS in the guinea pig.

A similar hope of finding a more sensitive indicator of damage than the hearing at 4 and 6 kHz is what has prompted extensive use of high-frequency audiometry (10 to 20 kHz) recently. Again, however, the evidence that would indicate clearly that ordinary noise may produce damage at these high frequencies before showing any effect at 4 or 6 kHz is still to be found. A couple of recent studies illustrate that the question is still debated: Gierek and Bielśka (1979) claim that damage appears at high frequencies first, especially in the first 3 years of employment, but Osterhammel's (1979) data lead him to state unequivocally that "HFA cannot be used as an early indicator of the traumatic effect of high-intensity noise." We shall hear more on this question shortly.

And, of course, there is the other side of the coin: threshold losses at certain frequencies may be found in animals with apparently normal hair cells in the appropriate place (e.g., Liberman and Kiang, 1978). This has led to study of the state of the cilia (Liberman and Mulroy, 1982) and of structures surrounding the hair cells in such animals (Slepecky et al., 1981; Salvi et al., 1982; Robertson, 1983). However, quantification of floppiness of cilia has so far not been achieved.

At the moment, therefore, the indicators of damage most employed continue to be the pure-tone threshold, especially in humans, and hair-cell destruction in experimental animals, both of which can be quantified. In experimental animals, obtaining reliable and valid behavioral thesholds is so difficult that only a few laboratories continue to attempt it, employing instead passive methods of inferring sensitivity, those based on computer-averaged electrical responses at various places along the auditory chain or inferred from study of many single neural units in a single animal. Agreement between results of brainstem audiometry and behavioral thresholds seems to be adequate (Henderson et al., 1983), providing that the proper shape of tone pips is used, even in animals with markedly frequency-dependent PTS (Borg, 1982a), so no doubt increasing use will be made of these "objective audiometry" methods.

Whether the "correct" index of damage is some measure of sensitivity or hair-cell destruction remains an unanswerable question, in the absence of a validity criterion, so it is not surprising that both have been measured where possible. Even though correlation may be poor between PTS and HC loss in individual animals, comparison of groups given different exposures usually shows that the exposure producing the greater average PTS also produces the greater average HC destruction, so that such group data will provide relatively firm evidence as to relative hazard.

Measurement of Exposure

Noise exposures come in an infinite variety of levels, spectra, durations, and temporal patterns. Attempts to establish a way to reduce all exposures, or at least most common exposures, to a single number continue: by field studies in humans, by experiment in the laboratory, and by decree at the conference table. The likely winner of this race appears to be the equal-A-weighted-energy theory: the proposition that damage produced in an initially-normal ear will be some monotonic function of (1) the amount of A-weighted energy absorbed by the ear during the work

day, provided that this energy is reasonably constant from day to day, and (2) the number of days, months, or years of such daily exposure. Let me emphasize that this is not a total-energy theory. A true total-energy theory would postulate that temporal pattern is completely irrelevant, while the equal-energy theory is more moderate, proposing only that the distribution of energy within the workday is unimportant, as long as the time integral of the square of the A-weighted sound pressure is constant. In short, the gross temporal pattern of ordinary human exposure--8 to 16 hours of noise with at least 6 hours of quiet--is built into the equal-A-weighted-energy theory. This is, of course, as it should be, since all the empirical formulas relating damage and exposure are based primarily on data that did in fact involve this temporal pattern, and it is the pattern which still seems to be of the greatest concern.

Human Exposures and Damage

Human audiometric data continue to be gathered. It seems to be a universal feeling that if a pile of audiograms exceeds a certain height, there must be a publication hiding somewhere inside. So cross-sectional studies continue to appear in which some group of people is alleged to be losing hearing from noise, but incorrectly so because the measured Hearing Threshold Levels (HTLs) are either not compared to any control group or, perhaps even more misleadingly, compared to an inappropriate control group. In the latter case, a common error is to "correct" each HTL by using age correlation tables that assume that the average person will have 0 dB HTL at age 18 or even age 25, instead of actual values of HTL displayed by a sample of individuals not exposed to the noise in question but with comparable sociacusic and nosoacusic histories (and, of course, of the same age and sex).

What appropriate control data have become available in the last 5 years? Unfortunately, few actual studies of the hearing of a randomly-selected non-industrial-noise-exposed population have been reported. A second study of a random sample of the U.S. population (Rowland, 1980) again failed to identify those persons who had been exposed to industrial noise, so that the remainder might serve as a suitable control population for inferring damage over and above that associated with ordinary living. The observed values of HTL at 500, 100 and 2000 Hz by age and sex were nearly identical to those measured 13 years earlier (Glorig and Roberts, 1965) and to those subsequently reported by Gatehouse et al. (1982) in a random sample of the population of the U.K. Although the new USA study showed about a 6-dB improvement in sensitivity at 4 kHz (3 and 6 kHz were not measured) over this period, one suspects that an error in calibration was involved, probably in the later study, as the U.K. data agreed much more closely with the earlier USA results. It may be, of course, that the inclusion in these random samples of a few persons with some industrial exposure will not bias the results enough to make the median data inappropriate for comparison purposes. That, at least, is the implication of the results of attempts by Royster and his colleagues (Royster and Thomas, 1979; Royster et al., 1980) to measure a semi-random sample of individuals in North Carolina who had not worked in a noisy industry for more than 2 weeks. Their results were almost identical to the original 1965 PHS data. Thus for the USA and the UK, one can estimate the additional PTS caused by the noise exposure concerned, providing the audiometric procedures were the same as in the surveys in question. The necessity for an adequate control group from the same country, however,

seems to be underscored by vast differences between the above data and some control measurements made in developing countries (Oleru, 1980; Ambasankaran et al., 1981).

When viewed critically in regard to controls, human audiometric data from cross-sectional studies have provided little new information on the relation between exposure and loss. Although hearing losses can always be found, they appear to be no greater nor more numerous than controls in, for example, musicians (Petrovic et al., 1979; Axelsson and Lindgren, 1981), mine locksmiths (Janisch, 1978), modern college students (Carter et al., 1978), children who live near airports (Fisch, 1981), incubator babies (Stennert et al., 1978; Winkel et al., 1978; Stewart and Abramovich, 1979), hearing aid users (Markides and Aryee, 1978), or even ambulance personnel (Johnson et al., 1980) and fire fighters (Reischl et al., 1981) who are exposed for short periods to siren noise at up to 115 dB SPL and whose daily 8-hr equivalent levels ($L_{eq(8h)}$) may near 100 dBA.

Even those cross-sectional studies that do show a relation between industrial exposure and hearing loss merely confirm the general empirical relation found earlier--i.e., that on average, 90 dBA of steady noise produces hearing loss at 3, 4 and 6 kHz, that 85 dBA is associated with a statistically-significant change at these frequencies, and that 80 dBA is without effect. Perhaps the fact that an $L_{eq(8h)}$ of 80 dBA is innocuous should not be particularly surprising, in view of the fact that this is just about the average daily sociacusis exposure of American adults (Schori and McGatha, 1978). Indeed, children both in the USA and in Sweden are exposed to $L_{eq(8h)}$s of 85 to 88 dBA in their ordinary activities (Siervogel et al., 1982; Garding, 1980).

One would hope that results of longitudinal studies of hearing might be less equivocal, since the HTL at the beginning of the studies would be at least approximately known. Unfortunately, however, the number of longitudinal studies is surprisingly small, although this will probably increase as hearing conservation programs become increasing automated and computerized. Royster et al. (1980) stress the fact that if no progression of hearing loss is actually occurring, then a slight but often statistically significant mean improvement in thresholds (2-3 dB) is to be expected at the second annual test, some sort of learning effect. A similar improvement was noted by Smith et al. (1980) and Brown (1982), although of course by 5 years this learning has been more than cancelled by presbyacusis, sociacusis and nosoacusis (Pell et al., 1982).

Furthermore, even the few longitudinal studies that have implied loss over and above that observed in a non-industrial-noise-exposed population have produced some rather strange results. In particular, a comparison by Howell (1978) of audiograms taken 6-8 years apart on 449 male steelworkers who used no ear protection showed that the progression of hearing loss, which was quite moderate (about 1 dB/year), was independent of the initial HTL--men with HTLs of 25 dB or greater at the time of the first audiogram showed neither more nor less additional loss than those with normal hearing.

The foregoing discussion provides ample evidence that the main trouble with all studies of the hearing of workers is that their sociacusic and nosoacusic exposures (a) often are completely unknown, (b) usually can be only roughly estimated, and (c) always are uncontrollable. Let us turn therefore to animal studies in which these influences can be eliminated or at least minimized, so that exposures are known, although the question of extrapolability of the results to humans complicates the picture.

Animal Exposures: Total and Equal Energy

If the proposition that damage is a function of the total energy of the exposure--the total-energy theory--has any merit at all, it is in situations in which recovery processes are minimized, namely, for single uninterrupted exposures. The theory has in fact been shown to apply to such exposures, but only for short durations of high intensities, i.e. in acoustic trauma. Experiments with guinea pigs by Voldrich and Ulehlova (1982) and by Axelsson and Vertes (1982) support this conclusion. To determine to what extent the total-energy theory was applicable to more moderate intensities, our laboratory has been systematically exposing groups of chinchillas, over the past 5 years, to a 2-octave-wide band of noise centered at 1400 Hz at various levels from 78 to 120 dB SPL and durations from 22 minutese to 150 days, measuring both behavioral changes in threshold and HC destruction. The results of these single exposures was straightforward: equal values of energy gave rise to equal hair cell damage and PTS for all exposures involving levels below about 112 dB (Ward et al., 1981). Specifically, the same damage was produced by 150 days at 82 dB, 15 days at 92 dB, 1.5 days at 102 dB, or 0.15 days (220 min) at 112 dB. Furthermore, all these results could be represented by a single curve given by $\%DOHC = \sqrt{E/25}$, where E is in joules/m^2. This growth function fits fairly well some data gathered by Bohne and Clark (1982) using increasing durations of 350-700-Hz noise at 95 dB SPL. Thus when recovery processes are minimized, we find that the damage is determined by the total energy, although not proportional to it: since the energy is proportional to the square of the pressure, the damage is proportional to the pressure (and to the square root of the duration). It is interesting that the just-safe single exposure of 25 J/m^2 is approximately 90 dB for 8 hr.

Ours seems to be the only study that has investigated the total-energy principle for exposures longer than 8 hr, so that measurable losses can be produced by moderate intensities. However, several laboratories have employed daily or standard-work-week exposures, so that a beginning has been made on the question of the accuracy of the equal-energy theory. In our case, it was shown that breaking up the 15-day exposure at 92 dB into 45 8-hr exposures given on Monday through Friday for 9 weeks resulted in a reduction of about half in hair-cell damage (i.e., equivalent to a 6-dB reduction in level or a 4-fold decrease in exposure time). And, in an experiment just concluded (Ward, Turner and Fabry, 1983), the same result was found from 45 0.8-hr exposures at 102 dB. At the moment, therefore, it appears that the equal-energy theory is quite healthy. However, it must be noted that these were single uninterrupted daily exposures. A more convincing demonstration or denial of the accuracy of the equal-energy assumption will be provided by the results of the next exposure, in which the daily 48-min exposure at 102 dB will be replaced by 48 1-min exposures given once every 10 min. I must admit that I cannot understand why more laboratories are not comparing such multi-workweek exposures of equal energy, in view of the importance of such evidence in setting exposure standards.

The workday exposure schedule has been employed by research groups at Dresden (Herhold, 1977; Kraak and Hofmann, 1977), Syracuse (Henderson et al., 1979), Michigan (Moody et al., 1978), Göteborg (Borg, 1981), and Ohio State (Lim et al., 1982), but at none of these places has the question of equal or even total energy been directly addressed.

Critical Intensity, Acoustic Trauma, and Impulse Noise

That there is a discontinuity in the function relating exposure to damage, a "critical" point that divides acoustic trauma from what, for lack of a better term, we may call "ordinary" slow-developing NIHL, has been clear for decades. It is commonly believed that acoustic trauma reflects the effects of actual structural failure within the cochlea (Rauchegger and Spoendlin, 1981), while ordinary NIHL may be a result of exhaustion of metabolites. One can therefore expect that the rules of the game change at that point. Can this point, though, be characterized as a critical intensity (Price, 1981), a critical energy (Erlandsson et al., 1980; Nilsson et al., 1982), or a critical value of some other combination of intensity and time? Or, indeed, is the damage induced by supra-critical exposures so capricious that we despair of ever finding the key to successful prediction?

Although many exposure standards assume that it is intensity that is critical, and consequently ban all instantaneous intensities above that level, there really is no evidence to support such a truncation; with sufficiently short exposures, even the highest levels are innocuous. For example, Arlinger and Mellberg (1980) showed that exposure to 120-dBA-peak 40-microsec clicks at 10/sec, so that the L_{eq} was 95 dBA, did not produce the slightest effect. The lack of hazard of 160-dB impulses from cap guns is also well known. So the critical point is not just dependent on intensity. Other results, including our own, make it equally clear that it is not an energy that is critical either: a 22-min exposure at 120 dB produced massive (85%) hair-cell destruction and over 50 dB of PTS, despite an energy even less than that in 112 dB for 220 min, 102 dB for 2200 min, etc. In short, we know that the critical point represents neither intensity nor total energy, and can only hope that some fairly simple combination of intensity and time--perhaps I^2t or I^3t, since intensity seems to be more important than time--will prove to be critical. Or perhaps there are <u>two</u> critical points (Wagner and Berndt, 1981).

In the meantime, studies in the high-intensity realm continue to show that present exposure criteria are often incorrrect, even if they fail to prove the adequacy of some alternative theoretical model, or even to agree with each other in implications. For example, experiments by Salt et al. (1981) imply that the hazard from 132-dBA-peak impact noises may be accurately judged from the energy, but Buck et al. (1980) showed that the damage produced by an 18-sec exposure to noise at 146 dB (or by a 2-h exposure at 120 dB, which has the same energy) was much less than from 1800 10-msec pulses delivered once every 4 sec. In the latter case, the damage was not reduced, but actually enhanced, by intermittence. That impulse noise, as from gunfire, is completely different from impact and steady noises, as Kraak (1982) has long insisted, is also becoming clearer. Hazard does not increase monotonically with pulse duration but actually decreases when the duration is so great that Fourier analysis indicates that most energy lies in the low-frequency (below 500 Hz) region (Price, 1983). Buck (1983) obtained similar results--i.e., less damage was produced by 25 pulses with a given peak level but a duration of 1 msec than by the same number of pulses with the same peak level but a duration of .05 msec (hence 13 dB lower in energy). The complexity of the problem of impulse and impact noises, and of crest factor in steady noises, all complicated by the protective action of the middle-ear muscles, assures that years of patient and systematic research will be necessary before we have a good grasp of the role of the critical point. About the best one

can say of this situation is that, at least, an excellent summary of the factors deterining exposure standards for impulse noise does exist (Smoorenburg, 1982).

Individual Susceptibility to Damage

Although definitive research on the relation between exposure and damage must involve a long series of experiments using the same animal, the same noise spectrum, a fixed temporal pattern, and consistent measures of damage, study of individual susceptibility to damage may consist of a single experiment. Therefore such indices of predisposition to damage continue to be studied intensively, as each experiment can produce another publication.

TTS. The notion that the ear showing the greatest temporary threshold shift (TTS) from a given exposure will be the ear demonstrating the greatest PTS from a more severe exposure is one that seems so obvious that it can hardly be questioned. However, no animal studies have yet shown a reliable relation (e.g., Ward and Turner, 1982), possibly because individual differences among these animals seem to be less than in humans, and human studies are always complicated by the fact that we never really know that, for instance, all apprentices tested before beginning work and then again several years later have received the same exposure in the interim. However, to the extent that such an assumption is correct, Fritze (1981) seems to have shown a highly significant correlation, and Kraak (1982) claims the same for a study by Reichardt that is as yet still unpublished.

Gender. Although women generally have less inferred NIPTS than men, it is by no means clear that this represents an inherent difference in susceptibility. Welleschik and Körpert (1980) argue that because the rate of increase of HTL with time is the same in men and women of the same age even though their HTLs differ, it is not the case that men are more susceptible but merely that their ears "age" more rapidly. This, of course, tacitly assumes that a change from 10 to 15 dB HTL is "the same" as a change from 30 to 35, and their conclusion is no firmer than that assumption. Borg (1982) found no consistent difference in susceptibility between male and female rats, nor have any been reported in chinchillas, to my knowledge. So sociacusis remains, in my opinion, still the prime suspect in this mystery, although an inherent difference in susceptibility is of course possible. This comment applies as well to the results reported by Berger et al. (1978), who showed that women working in 89-dBA textile noise for 10 years accumulate less than 5 dB of inferred NIPTS at 4 kHz, while men working in the same environment end up with nearly 20 dB, as Passchier-Vermeer's growth curves predict.

Age. Whether or not the young, tender ear is more susceptible, or the young, healthy ear is less susceptible is still open to question in man, although the animal evidence seems to favor the "more susceptible" view in hamsters (Bock and Seifter, 1978), rats (Borg, 1982b), and mice (Henry, 1982). Welleschik and Raber (1978) conclude from the AUVA data that susceptibility does not change in adults, hearing loss progressing at the same rate in a given noise regardless of age.

Eye color. Reports continue to show blue-eyed noise workers to have worse hearing than brown-eyed ones (Carter, 1980; Carlin and McCroskey, 1980; Carter et al., 1981), although no differences are found in children (Roche et al., 1983). However, the differences are always small and so have little practical significance although the role of melaninization of

the cochlea may prove to be an important clue to the nature of the process of noise damage.

Conductive loss. Although it is possible that some types of middle-ear problems may render the inner ear more susceptible, on average a unilateral conductive loss is associated with less sensory damage, a conclusion recently reaffirmed by Chung (1978).

Cigarettes and whiskey and... Although Robinette and Brey (1978) indicated a slight enhancement of TTS by alcohol, we (Ward and Cushing, 1977) found no such effect, although variability of the listeners' responses increased markedly. Thomas et al. (1981), reporting a study conducted in 1963, indicate that naval aviators with impaired hearing (greater than 50 dB HL at some frequency) smoked 25% more cigarettes than those with normal hearing. This was confirmed by Chung et al. (1982), who showed a 5-dB mean difference in HTL at 4 kHz between the heavy smokers and non-smokers among the noise workers of British Columbia. There have been no studies in the past 5 years relating sexual activity and hearing loss, despite Fosbroke's observation 150 years ago, in one of the first discussions of susceptibility, that "some deaf people find their ears colder and deafer post coitum, an effect produced by other causes of general diminution of vigor" (Fosbroke, 1830).

Although bad habits seem to enhance susceptibility, do good ones reduce it? Apparently not. Willson et al. (1979) found no relation between 28 different indices of healthiness based on circulatory and gastrointestinal functions and hearing loss. Even good thoughts help only a little; Bosshardt and Hörmann (1979) had difficulty in showing a difference in effect between a desired noise and an undesired one.

Blood pressure. In studies of susceptibility, all too often it is naively assumed that ears with hearing loss must have been the more susceptible, those still normal less so. That is, differences in noise exposure at work and in sociacusic influences are assumed to be negligible. This questionable assumption has characterized much of the study of the relation between hearing loss and cardiovascular function (e.g., Sanden and Axelsson, 1981). Although the major concern has been with whether or not noise can cause hypertension, a question that belongs to a different Team at this Congress, it could be that hypertension will increase susceptibility to noise damage. So several studies of workers with hearing loss and varous blood pressures have been published, most of which show an insignificant correlation anyway (Lees and Roberts, 1979; Malchaire and Mullier, 1979), although Manninen and Aro (1979) are able to find a theoretical explanation of why workers with moderate losses had a higher average blood pressure than those with normal hearing, but those with severe losses did not. More convincing is the work of Borg (1982c), who showed that rats rendered hypertensive by putting a clip on one renal artery suffered no more damage from his 100-dB noise than normal rats. So even though spontaneously hypertensive rats show more damage than normal ones after a life of exposure (Borg and Møller, 1978), the increased damage is not caused by the hypertension.

Aspirin. McFadden and Plattsmeier (1983) believe that they have shown that aspirin increases susceptibility. However, their experiment provides a striking example of how data on allegedly synergistic effects must be interpreted with great caution. One of their listeners showed a TTS of 12 dB after a noise exposure. Then he was subjected to high doses of aspirin, which raised his resting threshold by 18 dB. At that point the noise exposure was repeated, and his threshold after exposure was 7 dB

higher, or 25 dB above the original pre-exposure threshold. Was this an example of synergism? It depends on whether the "TTS caused by the noise" is defined as being 7 dB, as I would say, or 25 dB, as McFadden insists--i.e., whether that TTS is less than the 12 dB in the first study, which would imply no synergism, or more than 12 dB, indicating synergism. Obviously animal experiments involving permanent damage are necessary to resolve the issue.

Pneumatization of the mastoid. Every 5 years, someone once again asks if degreee of pneumatization of the mastoid has any effect on susceptibility, apparently a quaint notion that has persisted since the turn of the century, when industrial hearing loss was believed to be caused largely by bone-conducted sound. The answer, of course, is always "no" (Rotermundt, 1981), although surgical removal of that mastoid certainly can pose a hazard to hearing (Sorri et al., 1982).

Species differences. A most important aspect of any work with animals concerns the relative susceptibility of different species, if the results are to be legitimately extrapolated to man. Saunders and Tilney (1982) have recently summarized the evidence on various animals. It is clear from the accumulated data on the chinchilla that it is much more susceptible than man to permanent damage, perhaps largely because of the much slower recovery processes that are always found. Indeed, this delayed recovery may mean that the chinchilla will not, in the last analysis, be a good model in which to study the effect of intermittence.

Amelioration of Effect

At the last Congress, the most promising medication for effective treatment of acoustic trauma was dextran, a low-molecular-weight substance whose injection lowered blood viscosity, thereby presumably increasing cochlear blood flow and accelerating recovery processes. However, an apparent bias could be seen in the reports acclaiming its effects, due to selection processes used to determine which victims of acoustic trauma were to receive dextran. This suspicion was confirmed by Eibach and Borger (1980), who found that treatment of any kind--they had four different combinations of injections, including dextran, and of ingestions of various witch's brews--had no more effect on degree of recovery than observed in a control group given oral glucose and injections of neutral saline.

However, the hope that increased cochlear nutrition will lead to enhanced recovery lives on in the form of carbogen. Carbogen (95% oxygen and 5% carbon dioxide) was shown by Joglekar et al. (1977) and Watter et al. (1980) to reduce the temporary and permanent damage produced by a given noise exposure in man and chinchilla. Although the human portions of these studies suffered from an error in test order (TTS while breathing normal air was always measured first), which is why I ignored the Joglekar et al. study five years ago, experiments by Patchett (1980) and by Brown et al. (1982) tend to confirm the advantage of carbogen, and Fisch (1983) got encouraging results with it in treatment of sudden deafness. It is possible, then, that there is a better treatment for acoustic trauma than simple quiet. However, the importance of quiet is emphasized by Voldrich (1979), who exposed guinea pigs for 5 min to a narrow-band 1-kHz noise at 145 dB SPL, followed in half the animals by 30 min of 90-dB noise, in the other half by quiet. The extent of cochlear damage was about three times

as great in the animals in which acoustic trauma was followed by the otherwise innocuous 90-dB exposure. This may well be one of the most important experiments in this review period, if his interpretation is correct: i.e., that the structural damage induced by the high-level noise allowed mixture of endolymph and perilymph through tears in the membrane that normally separates them, and that these tears will heal more slowly while the cochlea is in even moderate continual motion. The critical exposure level may well be the one that produces such breaks in the organ of Corti.

Conclusion

After this quick overview of about 15% of the papers dealing with noise-induced hearing damage since 1977, it is difficult to see just how our picture of the forest has been affected by these particular trees. Perhaps the major points are the failure to find a good psychophysical correlate of slight cochlear damage; the growing realization that sociacusis plays a more important role in determining the "just safe" exposure than previously believed, and that indeed it may be the source of most of what has traditionally been called presbyacusis (Lehnhardt, 1978); the success of the equal-energy theory in predicting permanent damage from all but impulse noises despite its failure to predict temporary threshold shifts; and the increased emphasis on the concept of the critical intensity in interpreting acoustic trauma. However, progress is also being made in areas whose discussion was precluded by temporal restraints, such as determination of the physiological substrate of TTS, evaluation of hearing protectors and improvement in techniques for ensuring their use, and the utilization of hearing aids by persons with noise-induced hearing losses. We shall hear about some of these areas, as well as the ones discussed earlier, during the rest of the morning.

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ACKNOWLEDGMENTS

Preparation of this review was supported by the Public Health Service, National Institutes of Health, through Grant NS12125 to the University of Minnesota and NINCDS Contract 81-04 with the Medical University of South Carolina.

MEASUREMENT AND RATING OF IMPULSE NOISE IN RELATION TO NOISE-INDUCED HEARING LOSS

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INTRODUCTION

Since the Third International Congress on Noise as a Public Health Problem, held in Freiburg (1978), impulse noise has been of international concern several times. In 1980, an International Symposium on Effects of Impulse Noise on Hearing was organized in Malmö. This symposium has been extensively reported in Scand. Aud. Suppl. 12 (1980) [1]. One of the most important results of this symposium has been the quantitative definition of impulse noise.

In 1981 an International Workshop on Impulse Noise was held in Southampton (reported in [2]). The main aim of the Workshop was to get sufficient support from experts in several countries for the revised version of the International Standard ISO R 1999. Considering the present state of knowledge the Workshop recommended further research with respect to impulse noise in the industrial and military situations.

The importance of the problem of impulse noise exposure is obvious from the Bolt, Beranek and Newman study, reported in BBN report no. 3271

(1976) [3]. This report shows that 70 % of the production workers in the U.S.A. are (occasionally) exposed to impulse/impact noise in industry. At the same time, the assessment of impulse noise exposure in relation to noise-induced hearing loss is a complicated problem. On the one hand the impulse noise phenomenon have complex physical characteristics (peak level, time history, frequency spectrum, repetition pattern) and usually the exposures of people vary widely from day to day. On the other hand, even if the present exposure can be described satisfactoryily, the exposures of the workers in their past are difficult to assess.

Apart from the importance and the complexity of the problem of impulse noise exposure, the question still stands whether further research is necessary. In the following chapter this question is answered in the affirmative.

Due to the complexity of the problem, it would be very advisible to start a co-operation in this field between a number of Institutes. To realize such a co-operation, a Dutch proposal for international research was presented to the Directorate General of Labour (DG V) of the European Communities at the end of 1981. Unfortunately, no financial priority could be given to this initiative. This congress in Torino seems to be the next opportunity to realize a co-operation. One important step further would be to come to an agreement on a rating method of impulse noise exposure. Such a method has been proposed in the third chapter of this paper. The method is as simple as possible and the measurements can be carried out with generally available equipment. The method has been tested in several industrial situations. At the congress, the results thus far obtained will be shown.

Since it was strongly felt that a rating method together with the

resulting measuring method should not be too complicated, the method does not take into account the time history (rise time/decay time) of impulses nor the spectral distributions. The method is limited to a rating of (equivalent) sound levels in dB(A) and to a simple description of the repetition pattern of impulses over a work day.

IS IMPULSE NOISE MORE DAMAGING THAN CONSTANT/FLUCTUATING NOISE?

In the ISO Standard R 1999 (which was issued in 1975 [4]) the basic quantity for the assessment of noise exposure with respect to hearing damage is the equivalent continous sound pressure level over a representative work time T (L_{AeqT} in dB(A)). In this paper, L_{AeqT} will be expressed shortly as equivalent sound level. In ISO R 1999, a work week has been chosen for T. According to ISO R 1999, the equivalent sould level is the descriptive factor for all different types of noise exposures at the work place: exposure to noise which is constant, fluctuating, intermittent and/or contains impulsive components. However, for exposure to impulse noise, a penalty factor of 10 dB(A) has to be added to the equivalent sound level measured or calculated. This means that impulse noise with a given equivalent sound level is supposed to cause permanent noise-induced hearing loss which is equal to the hearing loss from exposure to constant noise with an equivalent sound level of 10 dB(A) higher.

At the moment, ISO R 1999 is being revised. Also in the revision (ISO/DIS 1999/1) [5], L_{AeqT} has been taken as the basic quantity for the assessment of noise exposure with respect to hearing conservation. T is now taken as a representative 8-hour day. In principle, no penalty factor for impulse noise exposure is to be used. Only the following restrictions are made in ISO/DIS 1999/1: "Caution should be applied in the case of impulsive noise.

The prediction is based primarily on data collected with essentially steady noise. The application to impulsive noise represents at present the best available extrapolation. Some users may, however, consider impulsive noise up to 5 dB(A) more harmful than steady noise". Therefore, compared with ISO R 1999, a decrease in the penalty factor for impulse noise exposure from 10 dB(A) to at most 5 dB(A) is proposed. The consideration about this decrease is that measuring equipment has improved so much over the last years that nowadays the equivalent sound level can be measured without any measuring error in any situation, while formerly noise measurements were carried out with a sound level meter at slow response, giving an underestimation of the equivalent sound level for impulse noise measurements. Although ISO DIS 1999/1 did not get much support from the Member Bodies of ISO, the comments hardly concerned the assessment of impulse noise exposure.

Two critical comments, concerning impulse noise assessment in both documents, have to be made.
Firstly, even at the moment there are only a few investigations allowing definite statements about the long-term harmful effects of impulse noise exposure.
Secondly, in the documents the term impulse noise exposure is not defined.
Under firstly: On behalf of the Workshop about impulse noise held in Southampton W. Passchier-Vermeer prepared an outline of the relevant literature [6]. Table 1 gives the result. In 1981 there turned out to be only eight publications concerning noise-induced hearing loss from impulse noise, with sufficient data to compare these noise-induced hearing loss figures with those from constant noise. And even for Guberan's publication it is questionable whether the data should be used. At least, the

Southampton Workshop decided that these results should be deleted, since the investigation was not considered reliable. The Table includes more recent publications by Bovenzi and by Evans

* Original figures of $L_{Aeq,8h}$(imp) were 114 and 118,5 dB(A) resp. Based on a private communication from Sulkowski to Lempert [9] the figures were adapted accordingly.

**NIL: Noise Immission Level, equal to $L_{Aeq,8h}$(imp) + 10 log T, in which T is the total duration of exposure in years.

The table shows the names of the authors of the ten publications, comprising 17 groups of workers exposed to impulse noise or a combination of impulse noise and constant or fluctuating background noise. The type of industry or more detailed the type of activity with which the publications deal are also given. The third column gives the equivalent sound level of the impulses over a typical work day (indicatod by $L_{Aeq,8h}$(imp)). The noise-induced hearing losses of each of the 17 groups are compared by the authors with the noise-induced hearing losses which would have been caused by exposure to constant noise with an equivalent sound level equal to the total equivalent sound level to which the groups were exposed. Relations for constant noise are taken from [18] and [19].

The table shows that half of the 17 groups examined are exposed to impulse/impact noise from dropforging. This type of exposure is characterized by the large number of impulses/impacts per work day. The number of impulses/impacts reported varied from 6000 to 80 000 on a work day (repetition frequencies from 0.2 to 3.6 Hz).

The last columns of the table show that impulse noise with equivalent

Table 1: Comparison of noise-induced hearing loss from exposure to a combination of impulse noise and background noise with noise-induced hearing loss from exposure to constant noise.

Author	Type of industry/ Type of activity	$L_{Aeq,8h}$(imp)	NIHL from exposure to impulse noise and background noise compared to NIHL from constant noise with the same equivalent sound level over the work day		
			more NIHL	equal NIHL	less NIHL
Voigt [7]	building	76-100	X		
Sulkowski [8]	dropforging	109.5*		X	
"	"	112.5*		X	
"	"	100	X		
Passchier-Vermeer [10]	metal	90	X		
"	metal	93	X		
Rangelrooy [11]	metal	98	X		
"	metal	92		X	
Ceypek [12]	dropforging	116		X	
Atherley [13]	trimming	117-127NIL**	X		
"	fettling	112-120NIL**	X		
Atherley [14]	dropforging	110+118		X	
Guberan [15]	dropforging	100		X?	
"	dropforging	90-100	X?		
"	dropforging	90	X?		
Bovenzi [16]	punchpressing	95-97	X		
Evans [17]	metal	93-96	X		

sound levels of 100 dB(A) or higher causes noise-induced hearing losses which are more or less equal to those caused by constant noise with the same equivalent sound level. Impulse noise with an equivalent sound level over the work day of at most 100 dB(A) gives in all situations, except one described by Rangelrooy, more hearing damage than should be expected from the relations for constant noise. The exceptions presented by Rangelrooy concerns the only situation in which the contribution of the impulses to the total equivalent sound level was lower than the contribution of the slowly varying background noises. Apparently, the hearing losses in this situation seem to have been caused mainly by the background noises, whereas an extra hearing loss from the impulses has not been caused.

As an example, to make these results understandable, a model of the noise-induced hearing losses as a function of the equivalent sound level is presented in Figure 1.

Starting from the dose-effect curve for constant noise, the curve for impulse noise exposure is shifted by 10 dB(A). Above 110 dB(A), the same noise-induced hearing losses are caused by constant and by impulse noise. Maximum differences in noise-induced hearing loss occur between 85 and 95 dB(A). Therefore, although some researchers prove that exposures to very high equivalent sound levels result in the same noise-induced deafness, irrespective of whether people are exposed to constant or impulse noise, this does not necessarily apply to exposures to lower equivalent sound levels.

To the opinion of the author insufficient data about the harmful long-term effects of impulse noise are available at the moment, to give a definite statement. The data so far available show that caution should be

applied to the assessment of impulse noise, since exposure to impulse noise in the range most relevant for hearing conservation programmes (80 to 100 dB(A)) may be more damaging than should be expected from the equivalent sound level measured. Only further research will possibly be able to give a definite answer on the question whether impulse noise is more damaging than constant or fluctuating noise.

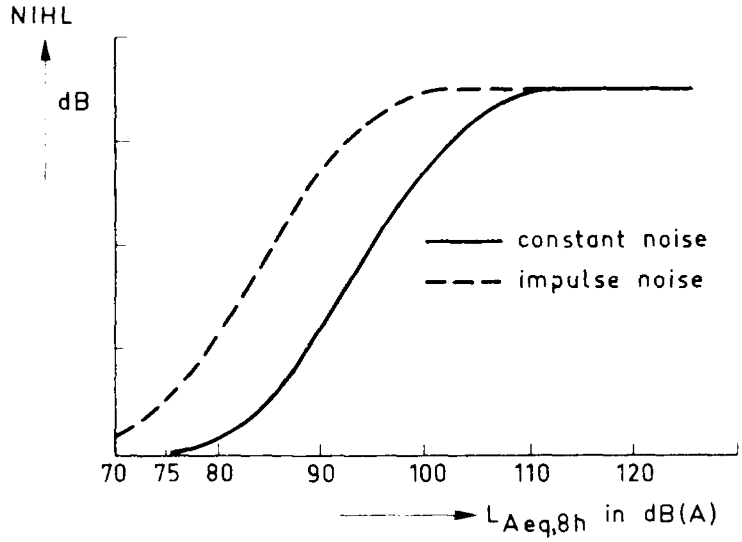

Figure 1 - Noise-induced hearing loss from exposure to impulse noise and from exposure to constant noise.

RATING METHOD

1. What is an impulse?

During the Workshop on impulse noise in Malmö a work definition of an impulse was given based primarily on common sense and available equipment. Before giving this definition, a new term should be introduced: Single event noise exposure level in dB(A) (L_{Ax}).

The L_{Ax}-value of one impulse is equal to the equivalent sound level (in dB(A)) referred/normalized to one second. For instance, if an impulse lasts for two seconds and the equivalent sound level during these two seconds is equal to x dB(A), then the L_{Ax}-value is equal to x + 3 dB(A). Would the duration have been $\frac{1}{2}$ s, then L_{Ax} would have been x − 3 dB(A). In this way, the energy contents of impulses can be compared by comparing their L_{Ax}-values, identically to the comparison of equivalent sound levels of different noise exposure.

In Malmö, an impulse was defined as a sound with:

$$L_{A,peak} - L_{Ax} \quad 15 \text{ dB(A)} \qquad ((1))$$

$L_{A,peak}$ is the maximum sound level occurring during the measurement. $L_{A,peak}$ can be measured with a sound level meter set at peak or peak hold (weighting time 50 − 100 μs) or with an oscilloscope, both equipped with an appropriate microphone. For industrial impulses/impacts it could be shown that both types of equipment give(nearly) identical results [20], [21], [22], [23].

If a number of impulses occur during the measurement of L_{Ax}, then

$$L_{Ax,t} \text{ (n imp)} = L_{Ax} + 10 \log n \qquad ((2))$$

where $L_{Ax,t}$ (n imp) is the measured $L_{Ax,t}$-value after a measuring time t (in seconds) in which n impulses occur.

2. What is impulse noise exposure?

Usually, at work places, exposure to impulses is accompanied by exposure to constant or fluctuating background noise. The total equivalent sound

level to which people are exposed is determined then partly by the impulses and partly by the background noises.

$$L_{AeqT}(tot) = 10 \log [10^{L_{AeqT}(imp)/10} + 10^{L_{AeqT}(bg)/10}] \qquad ((3))$$

in which: $L_{AeqT}(tot)$ is the total equivalent sound level over a period T

: $L_{AeqT}(imp)$ is the equivalent sound level over a period T due to the impulses

: $L_{AeqT}(bg)$ is the equivalent sound level of the background noise, in the absence of the impulses, over a period T.

The difference between $L_{AeqT}(imp)$ and $L_{AeqT}(bg)$is indicated by v:

$$L_{AeqT}(imp) - L_{AeqT}(bg) = v \qquad ((4))$$

The following tentative division can be made:

$v>5$: predominant impulse noise exposure $(L_{AeqT}(tot)-L_{AeqT}(imp)<1)$

$-5\leq v\leq 5$: combined exposure

$v<-5$: predominant background noise exposure $(L_{AeqT}(tot)-L_{AeqT}(bg)<1)$

Possibly, further research may show that the values of v equal to +5 and -5 dB(A) are not the best dividing figures.

Anyhow, the "impulsiveness" of a noise exposure is characterized by v. Further research will have to determine whether noise-induced hearing loss is dependent upon v. Unfortunately, the publications given in Table 1 could not be analysed in terms of v.

3. How can the repetition pattern of impulses be described?

Impulses may occur in a regular or irregular pattern during the work day. Impulses which occur regularly, such as in dropforging, riveting, ticking in a machine, surges of escaping compressed air usually are induced mechanically/electrically. These impulse trains may occur during the whole work day (that is with punch presses) or a part of the work day (namely riveting). Examples of impulses with an irregular pattern are those caused by hammering at metal or wooden objects, dropping of metal objects or in general impulses that are generated by isolated events. Usually these events are induced by manipulations of people [23].

The occurence of impulses can be characterized, according to [23] by

- the total number of impulses per work day (N)
- the total time (in seconds) of the work day during which the impulses occur (T') (For isolated impulses which may occur during the whole work day, the total time T'is 28 800 s (8 hours)). For regular impulses the repetition frequency can be calculated by dividing T' by N.

MEASUREMENTS OF THE RATING VALUES

In the foregoing chapter the following rating values were introduced: $L_{A,peak} - L_{Ax}$, $L_{AeqT}(tot)$, $L_{AeqT}(bg)$, $L_{AeqT}(imp)$, v, N and T'.

The integrating sound level meter allows a direct measurement of the equivalent sound level during any preferred measuring time during a work

day. If care is taken that the dynamic range has been adjusted correctly, the integrating sound level meter can be used for the measurement of L_{AeqT}(tot) of all types of noises, including impulses. Most integrating sound levels also have adjustments for measuring $L_{A,peak}$-values and L_{Ax}-values. If background noises are negligible, the measurement of L_{Ax} of impulses is straightforward. However, if the situation is such that the impulses are superimposed on relatively high background levels, then the measurement of L_{Ax} is rather complicated.

If $L_{Ax,t}$ is the measured value over a time t (in s) then:

$$L_{Ax,t} = L_{Aeq,t} + 10 \log t/t_o \qquad t_o: 1\ \mathrm{s} \qquad ((5))$$

Further, analogously to ((1)) the following equation is applicable:

$$10^{L_{Ax,t}(tot)/10} = 10^{L_{Ax,t}(imp)/10} + 10^{L_{Ax,t}(bg)/10} \qquad ((6))$$

in which $L_{Ax,t}$(tot), $L_{Ax,t}$(imp) and $L_{Ax,t}$(bg) are the measured L_{Ax}-values over a measuring time t related to the total noise exposure, the impulses and the background noise respectively.

In general, two situations can be distinguished:

- the background sound level (L_{AeqT}(bg) is known. If this level is much lower than the equivalent sound level of the impulses, L_{Ax} can be directly determined from $L_{Ax,t}$ by using ((2)) and the number of impulses n during the measuring time. If the background noise level is not negligible, the measured value of $L_{Ax,t}$ will in part be due to the background noise and in part to the impulses. The contribution of the background noise ($L_{Ax,t}$(bg)) can be determined then from $L_{Aeq,t}$(bg)

and t by using ((5)) and $L_{Ax,t}$(imp) can be calculated from ((6)) and L_{Ax} from ((2)).

- the background sound level is unknown. This may occur when the impulse noise source cannot be switched off/taken out of order and the impulses are so frequent that noise measurements during the time between the impulses cannot be carried out; then $L_{Ax,t}$ should be measured at least two times and the results analyzed numerically or graphically.

When the L_{Ax}-value of the impulses is known, L_{AeqT}(imp) can be calculated according to:

$$L_{AeqT}(imp) = L_{Ax} + 10 \log \frac{N}{T} \quad dB(A) \qquad ((7))$$

in which T is expressed in seconds.

The values of N and T' can be determined by using, for example, level recorders, from which N can be determined for isolated impulses and T' for impulse trains.

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CONCLUSIONS FROM ANIMAL EXPERIMENTS ON THE EFFECT OF STEADY-STATE AND IMPULSE NOISE.

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INTRODUCTION

Most of the noise to which people are exposed is complex in its nature with large changes in frequency and temporal composition and this is particularly the case with impulse noise. There is a great need for a simplified presentation of sound levels for the assessment of the effects of noise on the hearing of man as well as for the control of maximum acceptable levels e.g. in industry.

Based on empirical data on man, mainly from continuos noise studies, criteria with limited validity have been suggested (e.g. the ISO 1999 standard), which do not take the characteristics of impulse noise into account. On the other hand, the CHABA-report 1968,suggested a criterion for evaluating the relative hazard of impulse noise based on the peak pressure, the duration, and the number of daily exposures. However, in several countries modifications of the CHABA criterion are being used because the CHABA report was partly based on insufficient data (Smoorenburg,1982). The Equivalent sound level,L is the

result of efforts to simplify the evaluation of noise data. The introduction of the quotient q=3 is an electroacoustical simplification leading to a simple integration of energy over time in order to get an approximate equivalent steady state equal-energy level. Martin (1976) presented a typical set of data that is said to support the specific theory. In one example of hearing loss at 4 kHz in a population of drop-forgers,the level variation between the 25-th and 75-th percentiles is 22 -32 dB.

There is a similar variance in the data on most workers presented in similar studies (Burns and Robinson,1970). Much of the variability might be due to the fact that in most instances we do not really know what energy or what acoustic properties have entered each ear, particularly when data are based on stationary noise measurements (Håkanson et al, 1980). Besides the development of a permanent threshold shift (PTS) is not a linear function either of sound pressure level or frequency. Even if linear relationships may be found within limited areas, extrapolations outside such areas may lead to misinterpretations.

The effect of noise on the hearing of man is complex and it is well known that biological variations, which perhaps are hereditary, contribute to the sensitivity differences. The individual sensitivity to hearing damage caused by impulse noise as well as by continuous noise has to be considered. Until we can control the entire auditory history of the subjects it is not possible to control the variability due to individual factors. In man it is hard or even impossible to find known exposures whose effects can be measured, and for this reason we must use

animals whose exposures can be controlled. It is not possible to run experiments in man which might cause mechanical destruction to the ear or result in hearing loss.

In our studies of the relationship between noise exposure and permanent damage we used the guinea pig as a test subject, and evaluated threshold shifts and/or hair cell destruction as indicators of damage.

The aim has particularly been focused on the effect of systematically varying the different parameters of noise viz. intensity, time, and frequency on the permanent damage.

MATERIALS AND METHODS

Since the start of the experimental part of the project we have consistently used a strain of half-inbred pigmented blackeyed female guinea-pigs. In 450 animals we have never found any signs of otitis media or hereditary disease and there is a very low spontaneous hair cell loss. Details of the exposures and damage evaluations are described elsewhere (Erlandsson et al, 1980, Nilsson et al,1982) In short, groups of 5 guinea pigs were kept in a circular wire-mesh cage and exposed simultaneously to noise directed from above. Pure-tones of two different frequencies were used as continuous steady-state stimuli. The results of these experiments were evaluated after four weeks by computing the permanent morphologic damage done to the inner ear. For the impulse noise studies a synthesized click filtered through an equalizer and fed through an exponential horn was used. With this set-up it was possible to vary only one of the independent noise parameters at a time. Four weeks after noise exposure the VIIIth nerve compound action potential (CAP) was measured using tonepips for determination of the signal threshold (Nilsson and Grenner,1983) and the cochleae were then prepared and microscopically analyzed for hair cell loss (Nilsson et al, 1983). One unexposed controlanimal was processed with each exposuregroup. All results were compared to the pooled estimate of all control animals.

RESULTS AND DISCUSSION

A direct comparison was made between pure-tone and impulse noise exposures at either 38 or 152 Pa^2h equal total energy. The different parameters are given in Table I. The extent of inner ear damage in the apical turn (Turn 4) did not vary as a

function of sound intensity and was therefore not taken into account. It is apparent that the loss of IHC and of OHC was 2-4 times greater in the animals exposed to impulse noise compared to the animals exposed to pure-tones at both the energy levels. The occurrence of pillar cell collapse gave a contrary impression with a 4-6 times higher value in the pure-tone exposed guinea pigs compared to a very small number of collapses in the impulse noise- exposed animals .

Table I. Morphological damage to the inner ear in Turn 1-3 of groups (n=5) of noise-exposed guinea-pigs.

Exposure energy:	38 Pa^2h		152 Pa^2h	
" type :	Pure Tone	Impulse	Pure Tone	Impulse
" freq.(kHz)	1.33	0.8-2.5	1.33	0.8-2.5
" Int.(dB SPL or L)	102	102	108	102
" duration:	6h	6h	6h	24h
Inner H C loss (n)	15	66	45	179
Pillar C Collapses	23	6	28	5
O H C loss,%,mean	2.7	5.5	5.3	20.7
SD	0.6	4.4	2.5	7.3

Not shown in the table is another feature of difference between the two types of exposures i.e. the radial pattern of hair cell loss. This refers to the finding that with pure-tone exposures more OHC are missing in the 1st row than in the 2nd and 3rd. With impulse noise exposures more cells are missing in the 3rd than in the 1st or 2nd OHC-row (Nilsson et al,1980).

Very few comparative experiments are available in this context. The pure tone is a very specialized form of exposure and the ocurrence of rifts (pillar cell collapses) could be due to this fact. The described type of radial cell loss pattern is in agreement with previous findings following pure tone exposures (Robertson and Johnstone, 1980;Cody and Robertson,1983), where-

as Ward (1981) found a pattern similar to impulse noise when using a continous double octave noise band. One explanation for the observed differences may have come from Stockwell (1969) who noted that according to their results the OHC 1 was damaged most at higher exposure frequencies and OHC 3 most at lower stimulus frequencies .

There is of course also a spectral difference to take into consideration when comparing the two stimuli. The frequency of the pure tone stimulus is centered in the middle of the high energy part of the spectrum of the impulse which is located between 0.8 and 2.5 kHz.

However, it seems justified to compare these two types of stimuli when considering the basic question concerning the total energy rule and its validity. In this context the results indicate a more injurious effect of impulse noise at corresponding equivalent sound levels and total sound energy.

In fig 1 two series of pure tone exposures with different frequencies, 1.33 kHz and 3.85 kHz are plotted with the OHC-loss percentage as a function of sound intensity. Three findings are apparent: a. The change in sound intensity between 102 and 114 dB SPL did not result in any significant difference in OHC-damage. b. A Critical level,above which damage and individual variability increased in a nonlinear fashion seemed to exist somewhere between the stimulus intensities 114 and 117 dB for the experimental parameters used. c. Above the critical level there is a difference in damage extent as a function of frequency.

Also in the figure are given the the means and Standard error of the mean (S.E.M.) of CAP-threshold shift in the 10 ears from the five animals of each impulse noise exposure group as a function of stimulus intensity. With this kind of damage measurement the occurrence of a critical level seems to be apparent at roughly the same total energy. The L_{eq} was changed by means of varying the repetion rate by the impulse, which means that the repetition rate was very high at the 117 dB exposure (1,400/min). This high repetion rate is close to being regarded as a continuous noise, but according to the definition of impulse noise $L_{APeak} - L_{Aeq} > 15$ dB (Erlandsson and Jonasson, 1980) it could still be regarded as impulsive.

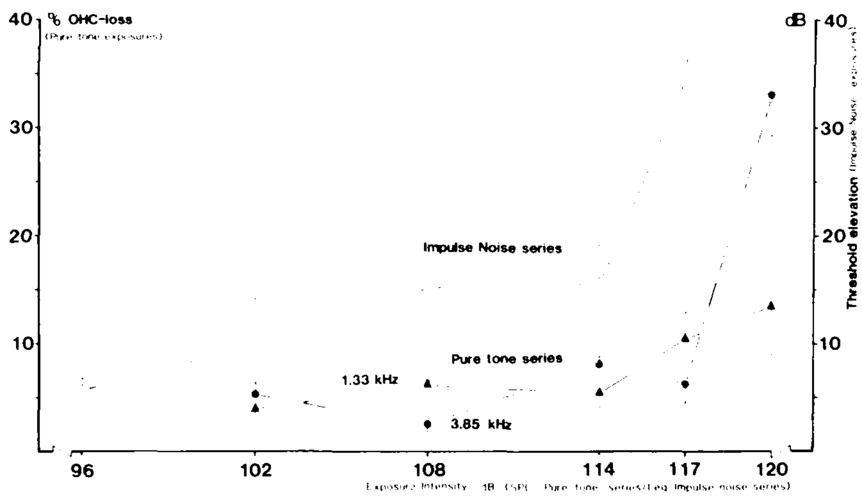

Fig.1.Mean value and Standard Error of the Mean (S.E.M.) of percent total OHC-loss (pure-tone series) or mean CAP-threshold elevation for frequencies 2-8kHz (Impulse Noise series) for groups of guinea pigs (n=5) as a function stimulus intensity. Exposure duration was 6 hours for all groups. Impulse peak level was 131.5 dB. The L_{eq} of the impulse noise was varied by changing the repetition rate of the click stimulus.

The existence of a critical level is fairly well recognized (Spoendlin and Brun,1973; Ward,1981). As earlier emphazised this level seems however not to be a function of intensity alone but also of the stimulus time (Erlandsson,1980). The relation between time and critical intensity seems to follow the equal energy concept.

In the pure-tone exposures there is not a monotonic relationship between OHC-loss and stimulus intensity, whereas there is a weak but steady change in CAP-threshold as a function of intensity change for the impulse noise series. The difference between the groups in our study may be difficult to explain because of the uncertainty in how loss of OHC correlate with increase in auditory threshold.

In fig.2 only results of impulse noise exposures are given. All 6 hour exposures are the same as those illustrated in fig.1. This is compared with other impulse noise exposures where durations instead of intensity were changed in groups of guinea pigs. Thus two different total energy functions are achieved, one by changing the noise intensity, the other by changing exposure duration. As indicated in the figure the slope of these regression functions are different.

At the energies corresponding to the critical level earlier discussed two more exposures were performed: one exposure where the 114 dB exposure was performed during 12 hours instead of 6 and one 117 dB exposure using 3 instead of 6 hours. The results show a definite threshold crossing at the total sound energy of 1200 Pa^2h. However, reduction of the exposure time to 3 hours

with the 117 dB-exposure gave a more serious damage than the

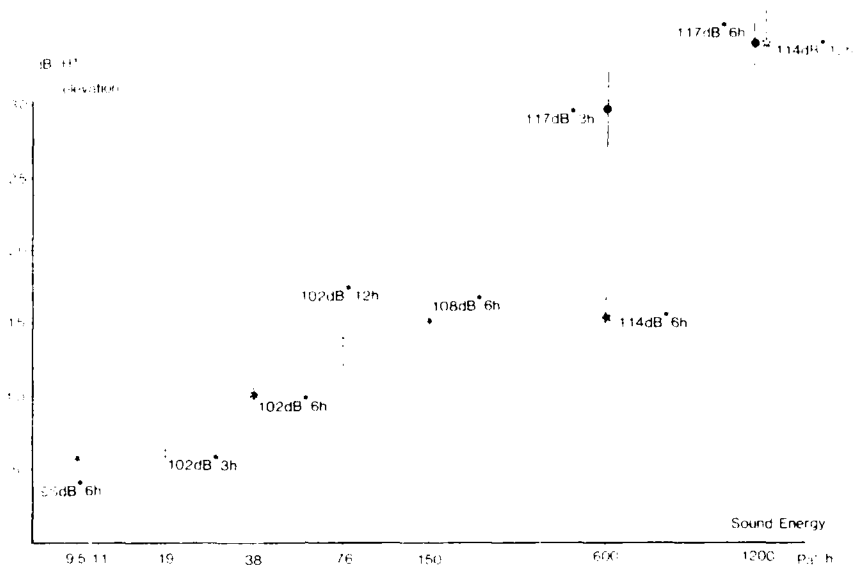

Fig.2.Mean and SEM-values of CAP-threshold elevation (mean value for frequencies 2-8 kHz) as a function of total sound exposure energy for impulse noise-exposed guinea pigs. Regression lines are calculated for the 6-hour series exposed to intensities below 114 dB Leq and for the 102 dB L_{eq}-series. Impulse peak level was 131.5 dB at all exposures.

114 dB 6h exposure ($p<0.01$). This is once again an argument against the equal-energy concept and could be due to the fact that at the critical level of energy the intensity might be the first determinator of damage.

We have described earlier the steeper slope in damage caused by extending the exposure time compared to increasing the stimulus intensity viz. below the critical level (Erlandsson, 1980). The implication of the difference in the slopes of the curves could be that different damage-mechanisms are in effect. The equal energy trade between intensity and time seems to be

valid only if one restricts the range of intensity or duration values.

In fig. 3 the results of a comparison between two groups of animals exposed to the same basic stimulus,(a 'hammerblow on wood'-impulse, peak-level=131.5 dB, L_{eq} = 102 dB,exposure duration 12 h) are given. One group was exposed in the anechoic chamber and the other group in a hard-walled (concrete) room. The B-duration in the anechoic chamber was 54 ms and in the concrete room 90 ms. The difference in the reverberation did not,however, reflect in a higher L_{eq} in the measurement of the exposures of the hard-walled room.

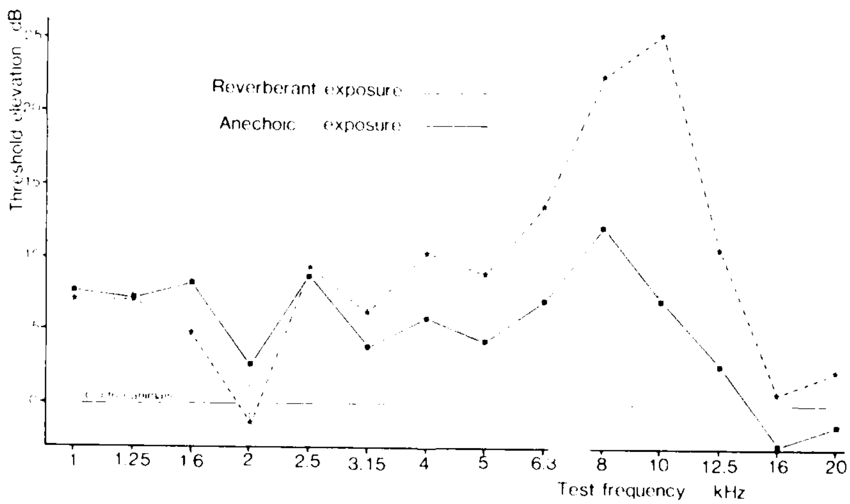

Fig.3. CAP-threshold elevation (mean and SEM-values; n=10) as a function of the tested 1/3rd-octave frequencies between 1 and 20 kHz. At each exposure a group of five guinea pigs were used.

There is however an apparent difference in CAP-threshold elevation between the groups (fig.3) indicating a more pronounced

damage in the animals exposed in the reverberating room. Regarding only the descrete frequencies tested, the threshold shift is only significant at 10 kHz ($p<0.001$). Taking all frequencies from 4 - 12.5kHz into account, the difference between the groups is significant at the 1% level. The finding is in agreement with Hamernik et al(1980), where these authors found very significant changes in the damage with only slight changes in the microstructure of the impulse, when considering both a reflected component as well as differences in the reverberation phase of the impulses.

FFT-analysis performed on both exposure occasions did not reveal any significant difference between thew two stimuli, which however ,might be due to the properties of the FFT-analysis.

CONCLUSION

The attempt to use a measure such as the L_{eq} - the equivalent energy value - is an oversimplification. When comparing stimuli of such extremes as pure tone with impulse noise we have found that impulse noise seems to inflict worse damage than does continuous pure-tone exposure - even at corresponding equivalent sound levels. The difference is even more striking when only the total energy is taken into account. These two kinds of stimuli yield different damage loss patterns which may be caused by different kinds of mechanical events in the cochlea.

For both types of stimuli a critical level, defined as a total energy exceeded, could be identified at roughly the same level, 600-1200 Pa^2h. However, higher intensity seems to have a more potent influence on exceeding the critical level than has long-

er exposure duration. Below the critical level any change in exposure duration seems to induce a different change in damage than does a change in stimulus energy.

Comparable exposures performed in anechoic and reverberating situations, not unexpectedly, gave rise to a difference in damage. However, there was no difference in the noise parameters ordinarily measured.

The experiments performed indicate that the equivalent sound level, L_{eq}, proposed with the q-value = 3 is an approximation with several limitations. A thorough understanding of these limitations might contribute not only to a deeper insight into the relations between exposure and damage but also to more efficient hearing conservation programs.

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HEARING LOSS IN WEAVERS AND DROP-F[illegible] COMPARATIVE STUDY ON THE EFFECTS [illegible] IMPULSE NOISE

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INTRODUCTION

Since the original proposal by Martin and Atherley /1973/ who have extended the equal energy concept /Burns and Robinson, 1970/ from steady-state noise exposure to evaluate industrial impulse noise in terms of its equivalent energy value, still unexplained question remains whether impulse and continuous noise have basically similar effects. The subject is of great importance in the process of developing procedures for the most appropriate estimating potential auditory hazard which as regard impulse noise makes the weakest point in present-day hearing conservation strategies.

Several studies, namely those by Atherley and Martin /1971/, Guberan et al. /1971/, Atherley /1973/, Ceypek et al. /1973/ including the rapidly repeated impulses of industry, generated by drop-forging, stamping, pneumatic chiseling have shown an essential equivalence of effect to that of an alike quantities of energy from steady-state noise.

Passchier-Vermeer /1981/, analysing the above mentioned data and others from the relevant papers /Rangelrooij, 1977, Voigt et al., 1980, Sułkowski, 1980/ have concluded that exposure to impulse noise with a very high equivalent sound level/L_{eq}/ of 110 dB-A or more does result in noise-induced hearing losses which are about equal to those from exposure to constant noise, and on the other hand L_{eq}'s over a workday of less than 100 dB-A does cause larger changes. Maximal differences in hearing losses from impulse noise or constant noise occur - according to the analysis by Passchier-Vermeer /1981/ - at equivalent sound levels in the range of 85 to 95 dB-A.

The significantly larger hearing threshold shifts after impulse exposure than after constant steady one were found among others by Dieroff /1961/, Acton /1980/ and Herhold /1980/; in the latter case concerning temporary threshold shift experiments in animals the difference was an approximately 6-fold. Other investigations, both of temporary threshold shift /TTS/ and permanent threshold shift /PTS/, have evidenced that for the same average hearing loss, impulse noise produces a wider spread of effect than does steady-state noise /Hamernik and Henderson, 1974, Kershaw et al., 1976/. Particularly excessive variability was observed in the field survey of impulse noise by Kershaw et al./1976/ and in our own reports /Sułkowski et al., 1980; Sułkowski and Lipowczan, 1982/.

Also, similarly to the clinical and field research, the patomorphological studies of the inner ear structure in animals have proved much greater variations of individual

cochlear damage with impulse noise exposure as well as worse damage as that produced by a steady-state noise /Spoendlin, 1976, Nilsson et al., 1980, Cody and Johnstone, 1980/. Unfortunately, the above quoted comparison of the results in losses due to two different kinds of noise failed to show any dependable distinguishing characteristics either, except slightly different radial patterns of outer hair cells damage /Nilsson et al., 1980/. On the other hand, in the case material of human temporal bones by Hawkins and Johnsson /1976/ there were seen a few signs to be argued that the pattern of injury by impulse noise including degeneration of cochlear hair cells in the first quadrant of basal turn may differ meaningfully from that produced in the second quadrant by continuous noise.

Some data suggest that perhaps there exist the distinct mechanisms of damage to cochlea due to both noises which differently influence permanent threshold shift; it is presumed that a moderate-intensity of about 100 dB SPL continuous noise develops mainly an biochemical deficiencies, while instead of an impulse noise induces mechanical destruction through a violent motion of the cochlear partition /Dieroff, 1980/. The assumption is supported by a few evidence reported for both monkeys and humans that there are basic differences too in the course of the physiological processes underlying TTS from continuous and impulse noise, resulting in the non-linear recovery pattern in the latter /Luz and Hodge, 1970/. If those two mechanisms could be

proved it may connote that different laws govern the relation between exposure and effect for the two forms of damage. By now, however, there is not yet any clear defensible evidence to separate impulse and steady-state noises, or their effects. Thus, further research should be continued on the mechanisms of noise-induced hearing loss based on PTS /TTS experiments are considered less direct predictors/ vs. noise exposure dose-response relationships.

The study presented, which involves data on noise levels and permanent threshold shifts at workplaces being a representative examples of steady-state and impulse noises is intended as a contribution for the better understanding the hazards of both types of exposure.

SUBJECTS AND METHODS

Two groups of workers, each constisting of only males and matched as closely as possible for age and their years of duty in the different noise exposures with the same equivalent sound levels, were employed. There were 112 cotton weavers /mean age 41.5 ± 10.3 years, mean exposure time 19.8 ± 10.4 years/ vs. 64 drop-forge hammermen /mean age 42.6 ± 10.5 years, mean exposure time 17.8 ± 9.6 years/. As a rule, they did not use ear protectors. Noise free population of the 169 age - /mean 35.2 ± 12.1 years/ and sex-matched persons of the industrial administrative staff served as controls.

All subjects were rigorously screened during otolaryngological examination; those with previous occupational or environmental noise exposure, medical history revealing conditions which may be related to a hearing impairment, and those with ear pathology were excluded from the final samples, Next, the pure-tone air and bone conduction audiometric tests were performed by a highly expercienced technician before beginning each workday in a sound booth ensuring measurements of 0 dB/ISO/ hearing level. The audiometer used was a manually operated Peters AP 6 with TDH 39 headphones calibrated daily according to ISO standards.

To assess the noise characteristics at workplaces of the subjects, field recordings of noise were made and then a laboratory analysis was performed; the special procedure

used for evaluation of impulse noise by means of a Bruel and Kijaer computerized data processing system has been described in details elsewhere /Sułkowski, 1980, Sułkowski and Lipowczan, 1982/.

NOISE EXPOSURE CONDITIONS

The continuous steady-state noise, as seen in Fig. 1, found in the cotton weaving mill was mainly produced by the work of picking motion of the shuttles; it had typical wide-band spectrum and the equivalent A-weighted level was 101.8 dB-A.

WEAVING MILL

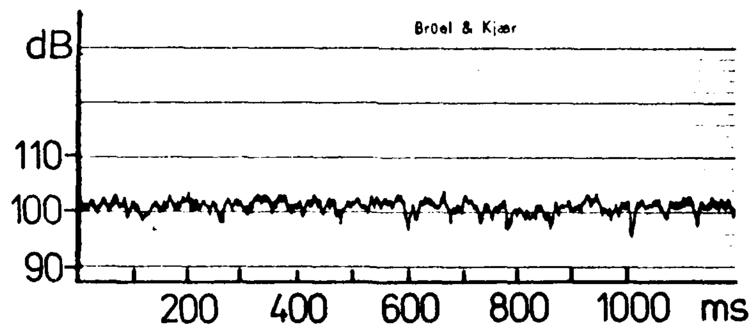

Fig. 1. Time history of continuous steady-state noise in the cotton weaving mill.

Nearly the same, namely 100.4 dB-A was the equivalent continuous noise level of impulse noise in the drop-forge, calculated according to the Martin and Atherley /1973/ method; impulses were generated by iron hammers with a stroke force of 100 tons falling from a height of approximately 1.5 m on an iron anvil; they were characterized by the

following parameters /average values/, as illustrated in Fig. 2: peak pressure level 110.7 dB, rise time 0.3 ms, impulse duration 30 ms, repetition rate per second 3.64, background noise level 92.1 dB-A, total number of impulses per day 80 000.

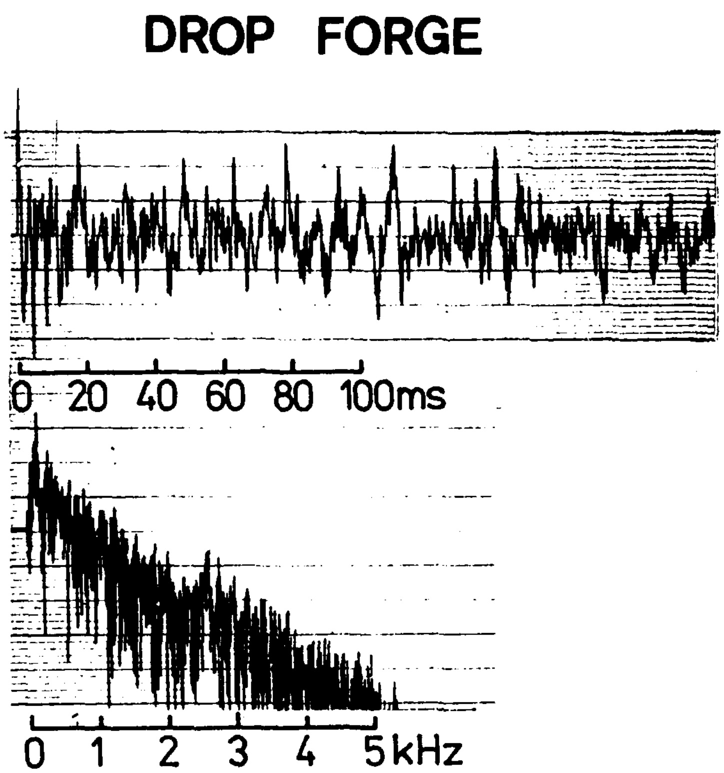

Fig. 2 - Time history and spectrum of impulse noise in the drop-forge.

AUDIOMETRIC SURVEY

A summary of the group results obtained from two noise exposed populations against controls is shown in Fig. 3, as the mean hearing thresholds with standard deviations. It can be seen that the locus of the maximum of the mean loss in

those exposed to steady-state noise was centered at 4 kHz versus greatest dip at 6 kHz in the impulse noise exposed workers. By contrast, the mean audiometric curve in controls was a quasi-flat and a slight high-frequency elevation of thresholds may be related only to usual effects of aging and sociacusis. Furthermore, the noise exposed groups showed much greater intersubject variability than controls resulted in a standard deviation within 20-24 dB in the 3-8 kHz frequencies range /against 8-15 dB in controls/. But the scatter of values was approximate in both noise exposed populations.

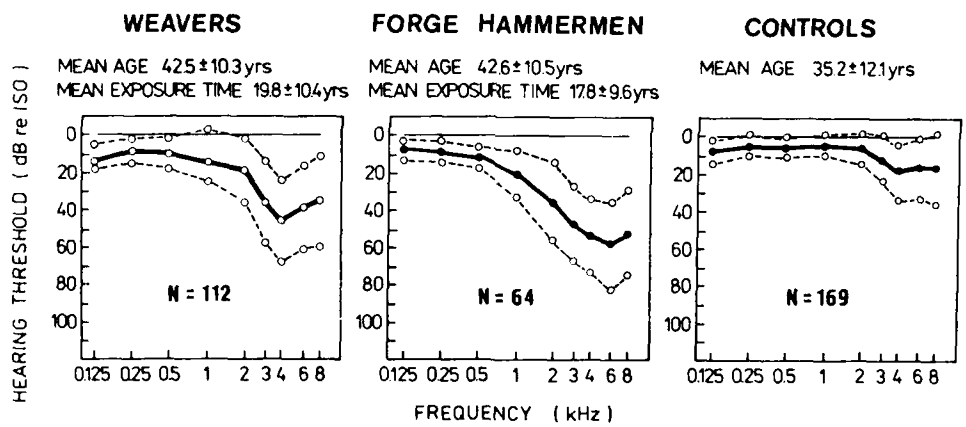

Fig. 3 - Mean hearing thresholds /——/ with standard deviations /— — —/ in weavers and forge hammermen versus controls.

It is also apparent from the Fig. 3 that hearing loss in hammermen was significantly greater than in weavers in the overall range of pure tone test frequencies and for instance respective mean values at 1 kHz were 20.0 dB vs. 12.3 dB, at 2 kHz 34.3 dB vs. 18.8 dB, at 4 kHz 52.3 dB vs. 46.0 dB and 58.8 dB vs. 39.1 dB at 6 kHz.

Next, the data collected were grouped according to the duration of exposure and the age of subjects and appropriate mean hearing thresholds have been plotted in Fig. 4-6, showing again worse damage in hammermen. As expected, the subjects of both noise exposed groups gradually over a period of years developed hearing losses which significantly increased with length of employment and consequently with age.

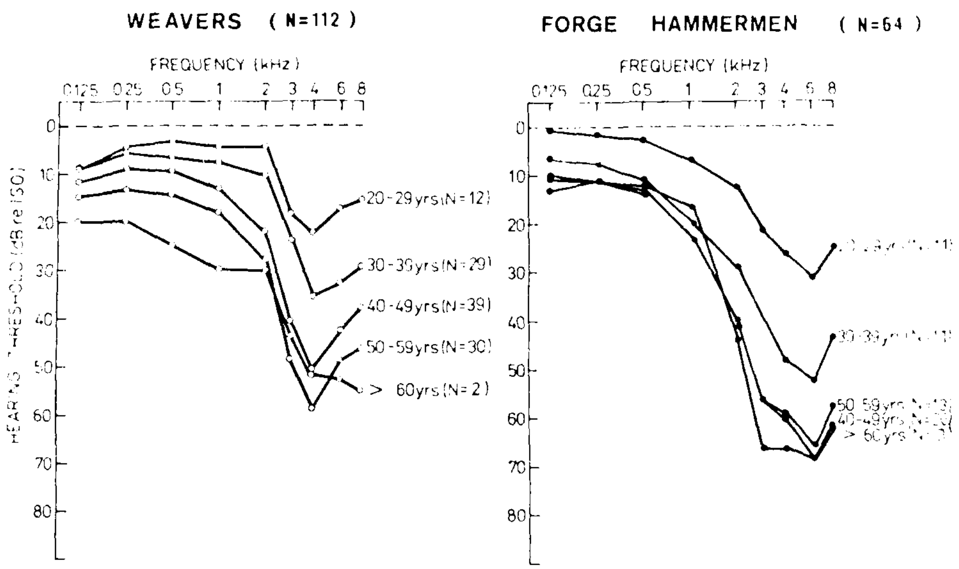

Fig. 4 - Mean hearing thresholds in weavers distributed by years of exposure compared with those in forge hammermen.

As can also be seen from the data, contrary to the age related changes, the hearing loss due to noise growed more rapidly in the younger age groups and apparently stabilised with advancing age.

The development of hearing loss in weavers compared with that in hammermen as a function of exposure time is

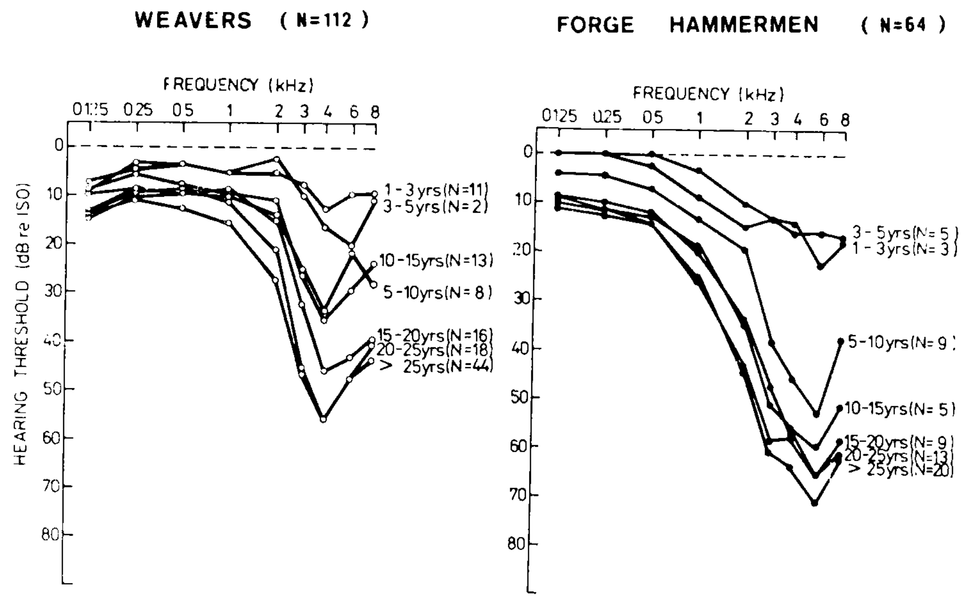

Fig. 5 - Mean hearing thresholds in weavers distributed by age groups compared with those in forge hammermen.

shown in Fig. 7. Besides a striking difference in the rate of permanent threshold shift there is clearly seen that its growth in both noise exposed groups turned out to be extraordinarily fast at first and next it slows down progressively throughout the whole of the subsequent exposure; only at 1 kHz the time course is very slow from the begining to the end and rather linear with years of work experience; the resulting hearing loss at this test frequency is slight against more severe losses at 2, 4 and 6 kHz. The significantly largest threshold shift develops at these frequencies during the initial 10 to 15 years of exposure both in weavers and drop-forge hammermen, after which it tends to slack up making the audiometric curve more smooth.

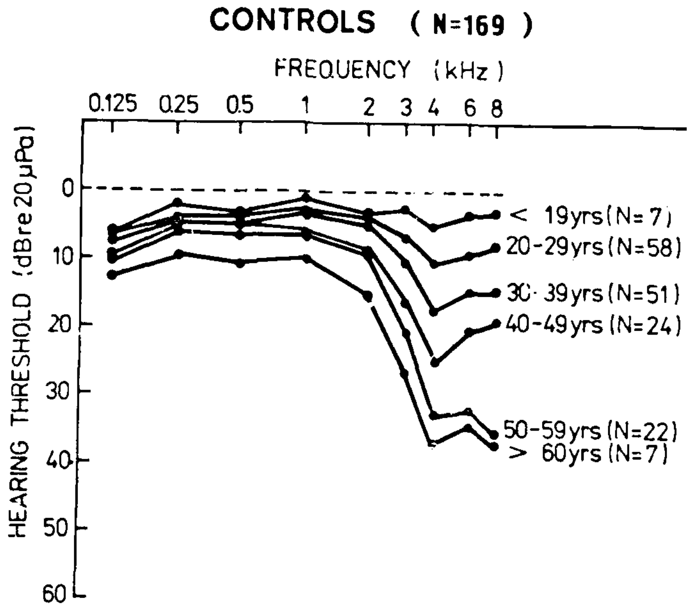

Fig. 6 - Mean hearing thresholds in controls distributed by age groups.

CONCLUSIONS

Reports of comparative exposure to continuous steady-state and impulse noise in the field conditions are rather sparse due to such objective reasons like difficulties with selection of age - and length of employment - matched populations not yet making full use of hearing protection, and the best of it is a hardness to find a similar, comparable noise exposures.

In the study presented it do succeed to surmount the obstacles and two screened and matched samples of cotton weavers and drop-forge hammermen exposed to typical

WEAVERS (N=112) FORGE HAMMERMEN (N=64)

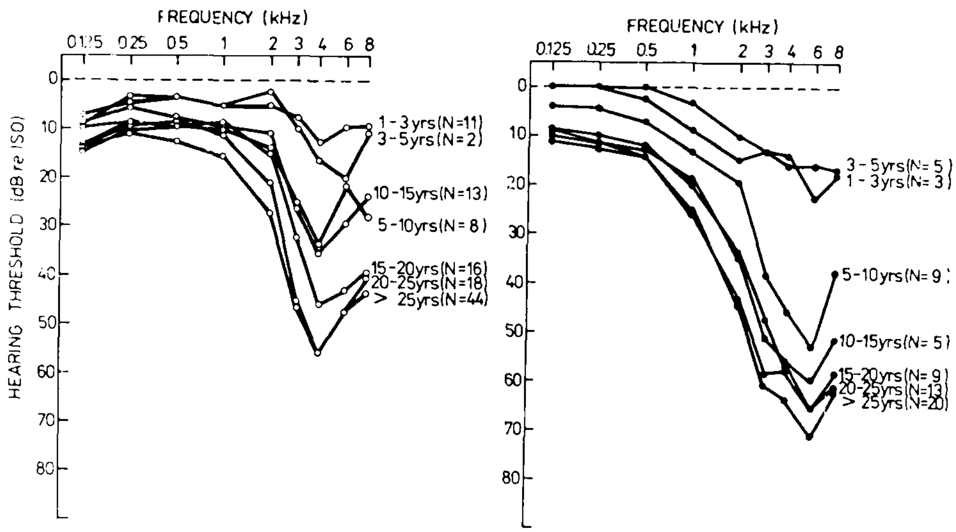

Fig. 5 - Mean hearing thresholds in weavers distributed by age groups compared with those in forge hammermen.

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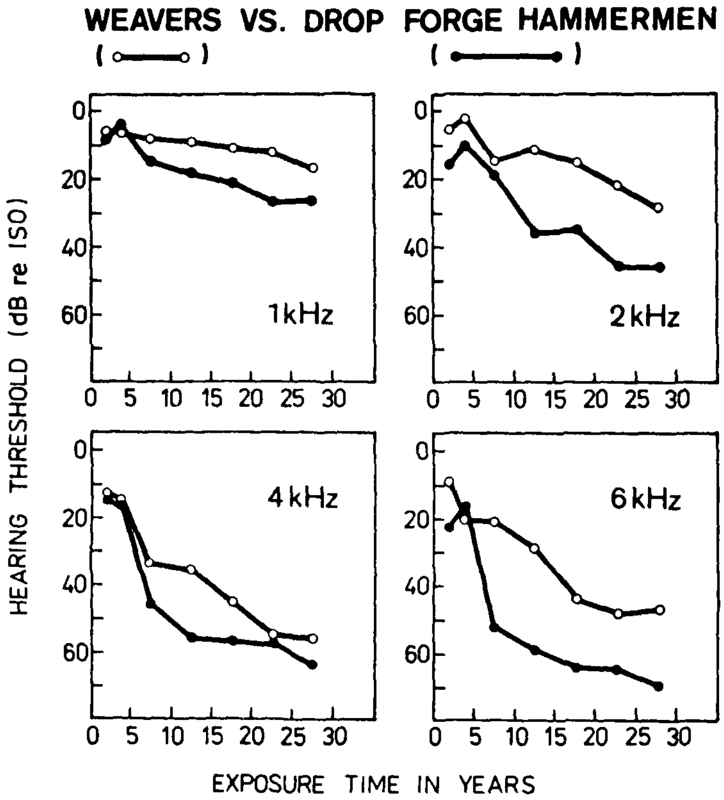

Fig. 7 - Mean hearing thresholds at 1, 2, 4 and 6 kHz in weavers versus forge hammermen as a function of exposure time.

industrial steady-state and impulse noise respectively, of the same L_{eq}, namely about 100 dB-A were carefully tested.

The results obtained suggest that hearing loss whatever is steady-state noise-induced or impulse one has a quite similar time course but a different extent of the rate, in spite of the same energy content of the both kinds of

exposure. Fully-developed permanent threshold shift occurs in the both cases after 10-15 years of duty and then rather stabilizes, reaching an asymptote by 20 years or so. It is worth of note, however that the shift is substantially less in weavers. The other significant finding which emerges from this study is unlike audiometric configuration in weavers versus drop-forge hammermen, observed as a group trend. It could be mean that impulse noise tends to produce greatest loss centered at 6 kHz, while continuous steady-state exposure results in a 4 kHz maximum. One may suppose therefore that the two classes of noise act in a different manner and their effect upon hearing, at least at equivalent sound level of 100 dB-A is diverse. Then, it seems rather not much reasonable to treat impulse noise as a part of "temporal" continuum of noise and to assess an auditory risk on the basis of the energy concept. In the light of our comparative study it is apparent that the impulse exposure of parameters described above is more traumatic than the steady-state one of the same L_{eq} and the impulse noise-induced hearing loss is not at all proportional to the amount of A-weighted sound energy.

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ACKNOWLEDGEMENTS

This study was supported in part by the U.S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control within the Polish-American Research Project PL 05-335-C /Principal investigator: Wiesław J. Sułkowski, M.D., Ph.D., Associate Professor/, and the Ministry of Health and Social Welfare, Warsaw, grant MZ-IX.7.25.

ACOUSTIC REFLEX AMPLITUDE IN RESPONSE TO CONTINUOUS NOISE AND IMPULSE NOISES WITH THE SAME ENERGY CONTENT.

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OBJECT OF THE STUDY

The object of the present study was to assess the amplitude of the stapedius muscle reflex contraction after subjection to fatigue in the form of an equal amount of acoustic energy administered with different modalities. For this purpose use was made of a continuous white noise, and bursts of white noise at several cadences.

MATERIAL AND METHODS

Five males and 5 females aged 20-25 yr with normal hearing were examined. Their air conduction tone threshold was not higher than 15 dB HTL for all frequencies between 125 and 8000 Hz.

Tests were carried out in a silent chamber with the subject seated in an armchair fitted with a head-restraint to prevent accidental alteration of the correct position of the sensor of the impedance meter. The data recording and processing equipment was located in an adjacent room so as to leave the subject in complete isolation. The test was run on the right ear of five subjects and on the left ear of the other five.

Signals were generated by an Amplaid MK VI adapted to receive data with outside software appropriately designed to obtain the type of stimuli required.

The Amplaid MK VI was connected to an Amplifon 702 impedance meter. This was adapted for connection to a Tektronix Model 5111 oscilloscope with 4 memory tracks for on-line recording of input data and monitoring of the output signal (fig. 1). A 220 Hz tone was used as the probe.

A standard TDH 39 headset was directly connected to the Amplaid MK VI stimulator.

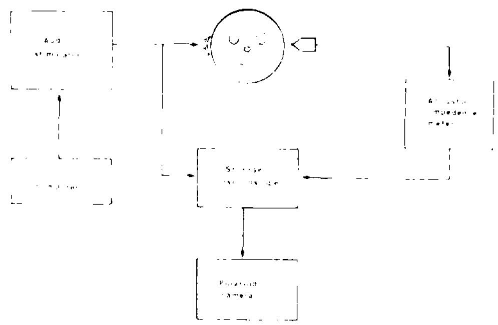

Fig. 1 - Instrumentation schematic.

Two types of stimuli were employed:

a) continuous white noise (90 dB SPL p.e.)
aa) 200 msec bursts of white noise with a 1 msec rise and fall time.

Six different burst exposure modalities were used (Tab. n° 1)

Cadence	Pause	Intensity	No. of stimuli
b) 0.2/sec	4,800 msec	104 dB SPL p.e.	180
c) 0.5/sec	1,800 msec	100 dB SPL p.e.	450
d) 1/sec	800 msec	97 dB SPL p.e.	900
e) 2/sec	300 msec	94 dB SPL p.e.	1,800
f) 3/sec	133 msec	92 dB SPL p.e.	2,702
g) 4/sec	50 msec	91 dB SPL p.e.	3,600

Tab. n° 1 - Burst exposure modalities.

Each fatigue test lasted 15 min. The intensity (L) was worked out in such a way that the same total energy content of the continuous white noise was delivered, irrespective of the cadence (fig. 2), using the formula:

$$L = L_{eq} - 10 \log \left(\frac{N\tau}{To}\right)$$

while the number of impulse stimuli (N) was obtained from:

$$N = \frac{To}{T + \tau}$$

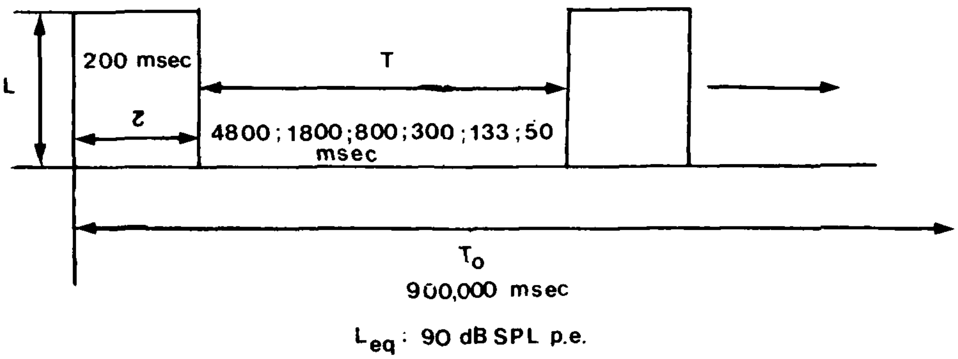

Fig. 2 - Modalities of the six different burst exposures used.

A Revox M 3500 microphone was used to determine the spectrum of the signal supplied by the ear piece. It was found that the maximum acoustic energy was delivered at frequencies between 1,500 and 4,500 Hz (fig. 3).

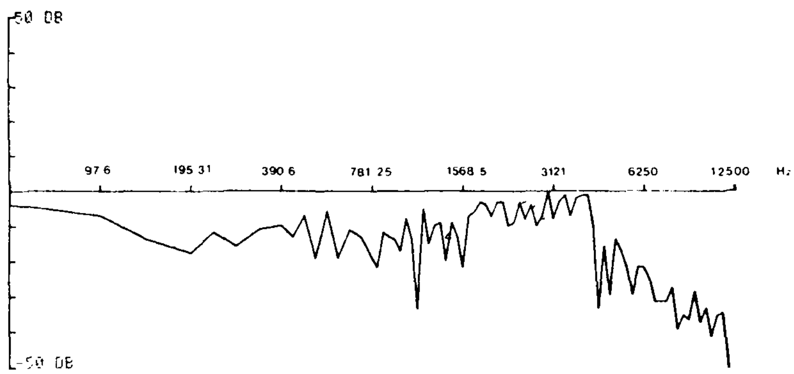

Fig. 3 - Headset signal spectrum (log scale FFA).

Contraction of the stapedius was detected during the continuous white noise test by interrupting the stimulus for 1 sec every 5' and evaluating the contraction amplitude when stimulation was resumed. The reflex memorised on the oscilloscope was photographed with a Polaroid camera at the start of the test, and after 5, 10, and 15 min. The photos were then enlarged 8 times to obtain more accurate measurement of the traces. Amplitudes were evaluated in arbitrary units on transparent graph paper.

RESULTS

The data were expressed as percentages of the values observed during acoustic repose prior to stimulation. The means for each experiment are indicated in Tab. n° 2 and plotted in fig. 4. In the text they are approximated to the nearest whole number. The findings in subject n° 5 are presented in fig. 5.

	Start	After 5 min	After 10 min	After 15 min
Continuous White Noise	100	79.89	80.32	64.83
Burst Cadence				
0.2/sec	100	97.45	93.22	94.89
0.5/sec	100	98.57	90.86	89.91
1/sec	100	85.80	73.71	65.78
2/sec	100	69.82	70.84	64.96
3/sec	100	43.23	42.40	38.02
4/sec	100	24.38	16.46	10.08

Tab. n° 2 - Mean % changes in acoustic reflex amplitude.

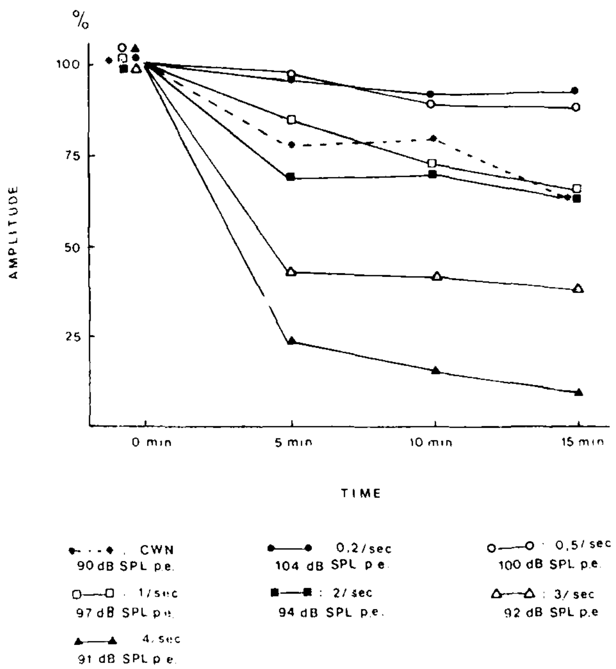

Fig.4 - Plot of mean % changes in acoustic reflex amplitude (start = 100%).

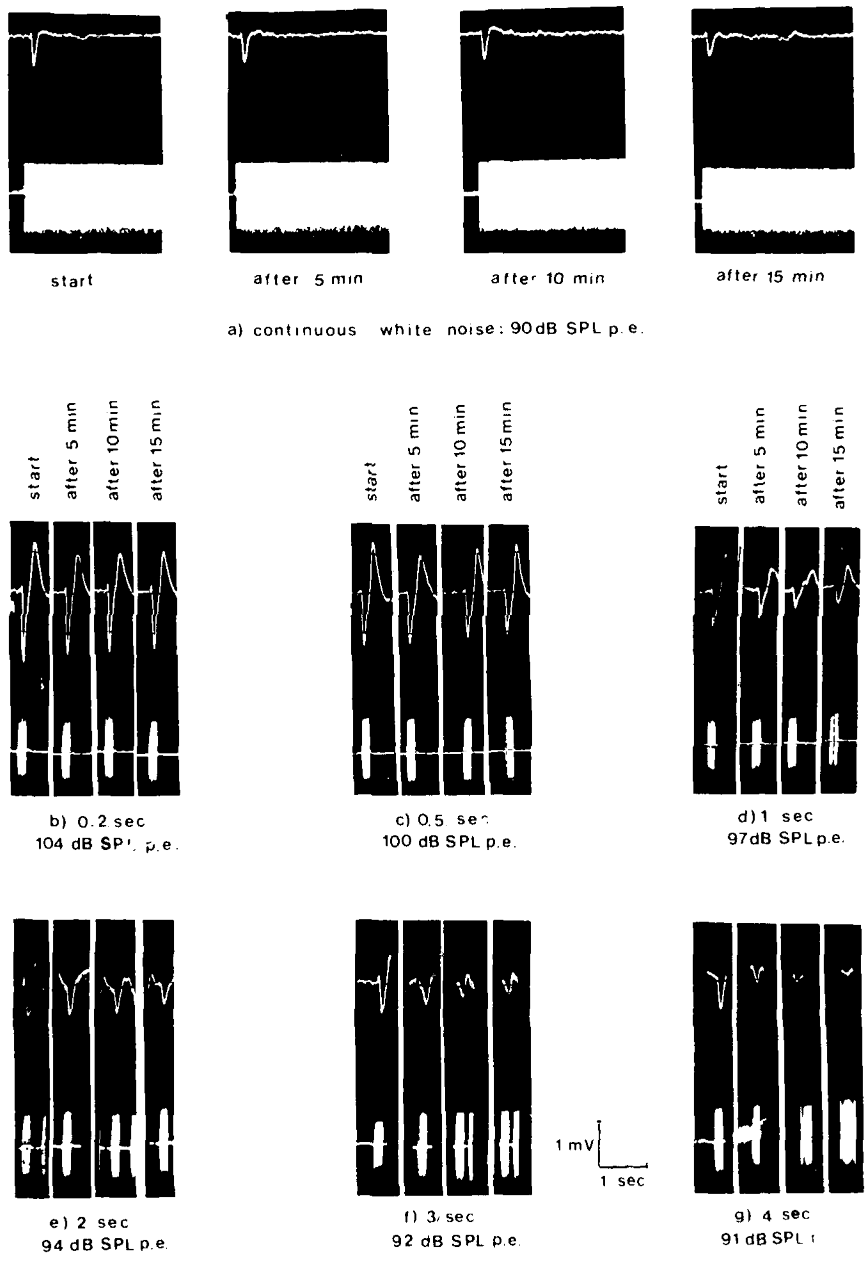

Fig. 5 - Findings in subject n° 5.

After 15' continuous white noise, there was a 35% reduction amplitude. The bulk of this decrease (20%) occurred in the first 5 min.

When bursts were administered, the pattern was much the same for cadences of 4,800 and 1,800 msec (i.e. one signal every 5 sec and every 2 sec). The respective maximum reductions were 5%, and 10% at 10' and again at 15'.

Different patterns appeared when cadences of less than 1 sec were used. When the pause was 800 msec (1 signal per sec), the decrease in amplitude was similar to that observed with continuous white noise: 14% after 5', 26% after 10', and 34% after 15' (35% after 15' continuous noise), though it was more regular and time - related. With a pause of 300 msec (2 stimuli per sec), the reduction was 30% at 5' and 10'. At 15', it was 35% - the same as at the end of both the continuous and the 1 stimulus per sec tests.

Significant patterns were noted in the last two burst tests. With a pause of 133 msec (3/sec), there was a reduction of 57%, followed by 58% at 10', and 62% at 15'. Lastly, with a 50 msec pause (4/sec), the reductions were 76%, 84%, and 90% respectively. It is clear that at 15' muscle contraction was virtually abolished.

CONCLUSIONS

These results suggest that,in our experiments,decreases in acoustic reflex amplitude in response to protracted noise with the same energy content, depend on the way such noise in presented. If the interval between each stimulus is at least 1,800 msec, there is virtually no decrease in amplitude.

When a pause of less than 1 sec is allowed between stimuli, on the other hand, after 15' a mean reduction of about 35% is observed when 1 or 2 stimuli are presented per sec (pauses of 800 and 300 msec respectively). Further shortening of the pause leads to even greater reductions: 64% with a pause of 133 msec (3 stimuli/sec) and 90% (i.e.

virtual abolition of contractility on the part of the stapedius) with a pause of 50 msec (4 stimuli per sec).

Continuous white noise leads to an oscilloscopic picture of rapid exhaustion of contractility (fig. 5a). The muscle is probably placed in a state of functionally inefficient tonic tension. Its energy reserves, however, are not exhausted. If the noise is interrupted for 1 sec, in fact, its fibres are able to contract, albeit with a reduction in amplitude, when it is resumed (fig. 5a).

The fatiguing effect, in other words, is more dependent on the modalities of administration of a noise than on its total energy content. Pulsed noises must thus be mainly defined in terms of their spacing, since their fatiguing effect may well be much less than that of a continuous noise with the same spectrum and energy content.

If this fatiguing effect were to be translated into reduction of the protection of Corti's organ, in other words a reduction in stapedius contraction amplitude resulting in a greater amount of acoustic energy reaching the inner ear, it would be obvious that hearing damage ascribable to noise is not a function of the amount of environmental acoustic energy, but of the amount of energy that gets past the middle ear and reaches the inner ear.

Given the same amount of ambient energy, therefore, the amount reaching the inner ear will vary in accordance to the time pattern with which such energy is delivered to the ear.

ACKNOWLEDGEMENTS

The valuable assistance of Prof. G. Sacerdote in the setting up of this research and of Dr. M. Rolando in the processing of the data is gratefully acknowledged.

THE VALUE OF THE HIGH-FREQUENCY AUDIOMETRY IN NOISE INDUCED HEARING LOSS COMPAIRED WITH THE CONVENTIONAL AUDIOGRAM.

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INTRODUCTION

The application of the high-frequency range of man between 8 and 20000 Hz for diagnosis is already very old. Zaardemaker (1891) used the Galton whistle and published some results about the hearing of high-frequency in old age. In 1912 the monochord was introduced as one of the instruments for ENT physicians by Struycken and recommended as suitable for the determination of the upper limit frequency up the 20kHz.Also the first electronic audiometer developed by Bunch in 1929 enabled us to determin the upper limit frequency. After the introduction of the audiometers into ENT medicine in the fifties the tests of high-frequency were more and more neglected. Thus ISO Recommendation 389 standard reference zero for the calibration of pure tone audiometer (1964) provided only a frequency range from 125 to 8000 Hz. The limitation to 8000 Hz is due to the fact that the measurement of high-frequencies meets with technical difficulties and the reproducebility of the hearing level above 8000 Hz is no longer reliable.At the end of the sixties the American firm Rudmose developed a high-frequency special audiometer showing likewise considerable deviations of intensity from one measurement to the other

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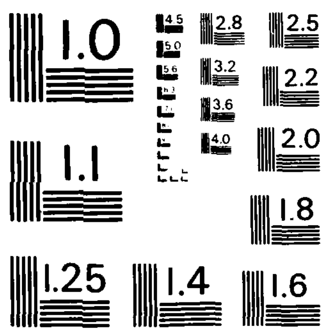

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

when critically checked though the procedure of Békésy was used. However,there was still the demand by ENT physicians to have a high frequency audiometer at hand which works in the high frequency range as reliably as the conventional audiometer between 125 and 8000 Hz.

METHOD

Improved receivers at the Rudmose-Audiometer with high fidelity loudspeakers have trough about very reliable measuring results after all. Berlin and also Bentzen recommend special loudspeakers, so hi.fi.headphones, which also allow a reproducible threshold tracing.P. and D. Osterhammel and co-workers have discribed a complicated quasi-free-field transducer system which likewise leads to usable results and is successfully applied by Filipo and co-workers. On the whole we may state that by using a testified technique the high-frequency hearing of 8000 to 20000 Hz may today be measured as reliably as the conventional hearing in the range beween 125 and 8000 Hz.

If we suppose that we may measure the high-frequency hearing as exactly as the conventional hearing the question arises which possibilities are offered by the application of two measuring procedures and which advantages the high-frequency audiometry has on the one hand and the conventional one on the other. Today the systematic investigations at the cochlea both in animal testes an in man allow a gapless histological examination of the whole cochlea. By using special procedures we are also able to measure the number of haircells and the hair-cell volumes. Intensive investigations have clearly proved in most cases that the basis of the cochlea (basal coile), i.e. the area near the window is especially endangered by all ototoxic matters and also by acoustic overload. At present histo-cytographical illustrations are used in cases of sound loads and also in the application of ototoxic matters to prove a beginning or progressing inner ear damage. Many individual observations are to be found in

literature and two marked illustrations by Johnsson,Hawkins and co-workers as well as by Jordan and co-workers show changes in the high-frequency range and also in the conventional range of the cochlea in cases of acoustic overload. To do honour to the histological illustrations, which today always show an exact picture of the histological relations from the windows to the helicotrema the demand may be raised to test the functional behaviour of the whole frequency range and the include into the audiometric examination the high-frequency range situated in the basis of the cochlea as an indicator for an early damage.

RESULTS

Adventages of high-frequency audiometry.

H.-f. audiometry offers big adventages for recognizing and judging early damage in the inner ear, since as already said the basis of the cochlea responds very qickly already with local inflammatory changes in the middle ear, but also with ototoxic metabolic damage of the whole organism in the form of hair-cell loss.

We may recognise the first changes very regularly in this frequency range near the window in cases of noise overload. 75 per cent of our examinations of noise-resistent persons selected for such experiments in the field of temporary threshold shift measurement had to be labelled as "noisesusceptible". This number is particularly interesting, as Meyerhoff could prove an affected middle-ear in examinations of children up to 6 years in about 75 per cent and more of the cases at least once during the age mentioned. In our tests of physical fitness concerning experiments in noise overload we could see, in many of the 75 per cent of cases mentioned above, slight tympanic residues and discrete, but clear changes in the high-frequency range occuring partially only on one side which indicated a former middle-ear affection. Already slight deviations in the high-frequency diagram with normal conventional audiograms must be regarded as an evidence of a previous damage, if a correct re-

gistration may be guaranteed,as this was the case with a man having served in the army as an anti-tank gunner (fig.1).

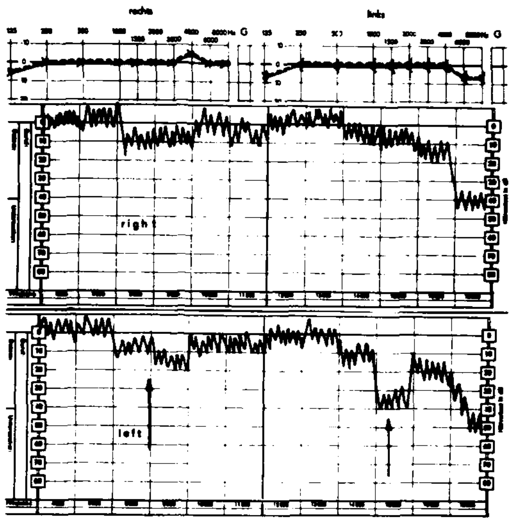

Fig. 1 - Normal conventional audiogram, and normal high-frequency audiogram right, but some small threshold shift at 6,8 and 15 kHz on the left side.

Especially convincing for the usefulness of h.-f. audiometry for proving early damage are observed temporary threshold shifts with 12 patients selected by means of the susceptibility test mentioned above. In these cases there also occurred quite different TTS patterns with equal sound dosis - L_{eq} = 90 dB(AI) - but with 6 quite different time pattern. With regular steady sound the changes about 4 and 6 kHz (fig.2) prevailed,in pulse noise to a higher degree the TTS in the high-frequency range (fig.3).
With vocational steady noise-overload (e.g. weaving noise) there are also visible the first symptoms of a developing PTS in the h.-f. range and about 4 - 6 kHz. With acoustic traumata (shot-overload and impulse noise) the h.-f. audiogram offers the possibility to define the damage in the h.-f. range what in our opinion may be prognostically used. Despite a similar hearing loss in the h.-f. range the da-

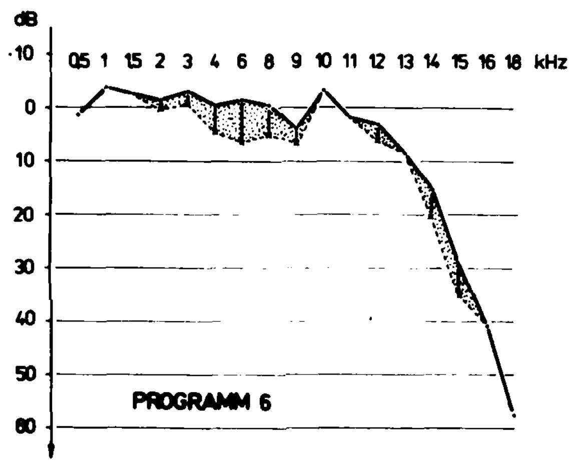

Fig. 2 - TTS (mean value from 12 normal hearing persons)
Noise exposure: 90 dB(AI), 1 hour, white noise

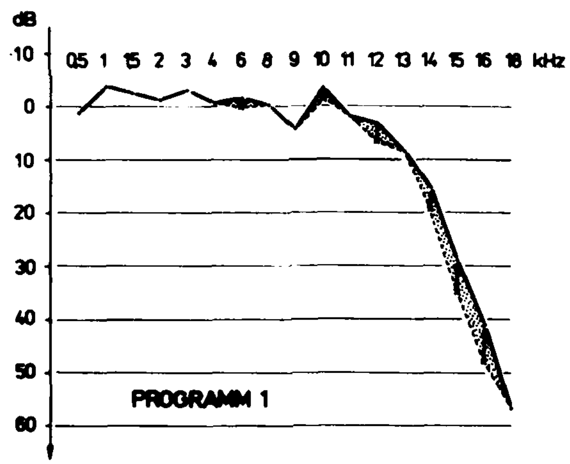

Fig. 3 - TTS (mean value from 12 normal hearing persons)
Noise exposure: 90 dB(AI), 1 hour, pulsed noise.

mage in the h.-f. audiogram may be very different.According to our experience the deep slopes with a completely destroyed h.-f. perception range are prognostically unfavourable, because with increasing age the progressive inner ear

degeneration develops more rapidly and takes in the hearing range for colloquial speech (fig. 4). On the whole on the

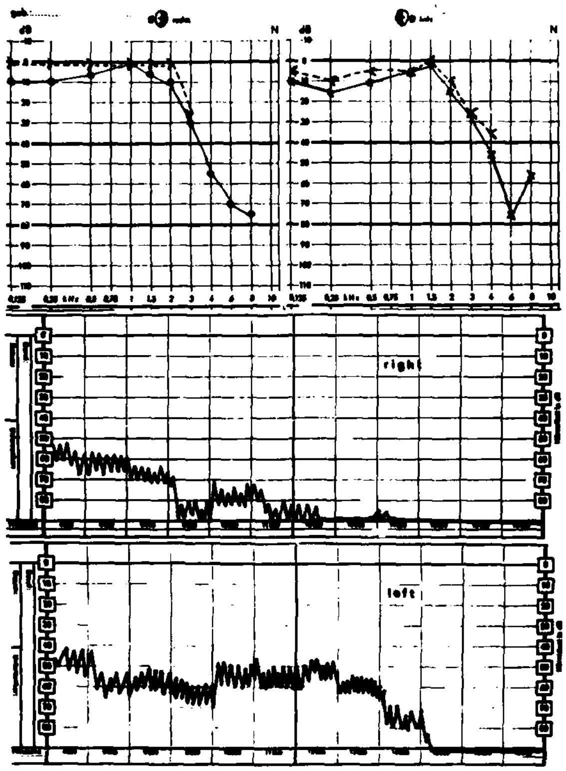

Fig. 4 - A 34 - year-old man with a acute acoustic trauma produced by anti-tank-shoot.

one hand early damage in the h.-f. range may be recognized by means of h.-f. audiometry, which mainly arises with acoustic overload, but also with the reaction of ototoxic agents, Ribári, on the other hand however, the method is very useful with the examination of hereditary hearing loss where the mediocochlear frequency range may show a bigger PTS, but the high-frequency hearing is still intact (fig.5). In our opinion such a behaviour may be estimated to be prognostically favourable. As we may see from the few examples the h.-f. audiometry makes possible the recognition

of previous and early damage in the struggle against noise-induced hearing loss and thus a better prognosis in evaluating inner ear damage than by means of the conventional diagram alone.

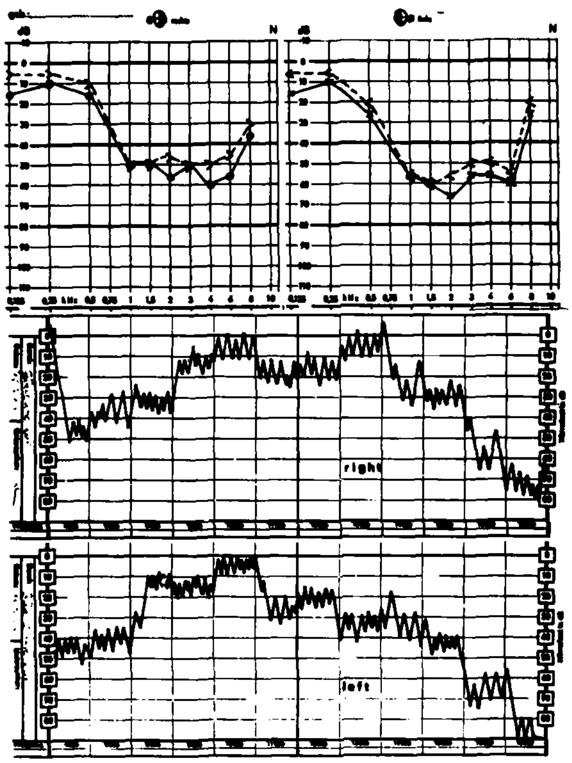

Fig. 5- Hereditary hearing loss of a 24-year-old woman with a big hearing loss in conventional hearing range and nearly normal high-frequency hearing.

CONCLUSION

After refering to the importance of testing the high-frequency hearing and the difficulties in sound coupling the progress in evaluating the damage of the whole cochlea is described. For the recognition and diagnosis of noise induced hearing loss high-frequency audiometry shows consi-

derable advantages and is recommended for early diagnosis and prognosis of noise-induced hearing loss.

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EFFECTS OF NOISE AND SOCIOECONOMIC FACTORS ON HEARING IMPAIRMENT

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INTRODUCTION

In 1978, Coles (1980) drew attention to an 'epidemiological study of deafness' commencing in the UK at the MRC Institute of Hearing Research. That study, the National Study of Hearing (NSH), has now been in progress for four years. Some preliminary results from early phases of the study have been published (Davis, 1983; Institute of Hearing Research, 1981 a,b). The aim of this paper is to provide interim data from this large-scale epidemiological study on two questions: (a) the audiological implications of recording subjects' noise exposure, as suggested by Dixon Ward (1980) and (b) the effect of such noise history and socioeconomic factors upon hearing impairment. Five aspects of the data will be presented. Firstly, I will give the various measures and sources of noise immission and their distribution with age, sex and socioeconomic group. Next, I will evaluate the effect of noise history on tinnitus, as assessed by a clinical interview. Thirdly, the relationship of noise history to the air-bone gap will be noted. Fourthly, I will summarise the causal and associated factors in hearing impairment emerging from a

long series of analyses. Fifthly, I will discuss possible interactions between factors, and some unsolved questions that point to future research and analyses.

METHOD

The outline design of the National Study of Hearing has been presented by Davis (1983) and by the Institute of Hearing Research (1981 a;b). Briefly, the study involves a two stage random sample. The first stage consisted of random selection from the electoral register of a total of 23,681 individuals in two Phases who received a screening questionnaire. The second stage clinic sample consisted of random selection from a series of ten strata formed from the questionnaire responses concerning age, hearing difficulties, tinnitus and possession of a hearing aid. All the data reported in this paper have been appropriately weighted such that the results refer back to the initial population, individuals appearing on the electoral register of Cardiff, Glasgow, Nottingham and Southampton. This is generally an adequate frame for inference to the total population of the sampled cities. The data were collected in two phases, in 1980, involving 759 subjects, and in 1981 when there were 895 subjects.

RESULTS

1) *Noise History*. Five measures of noise history were taken. The screening questionnaire asked whether the respondent had worked for more than six months in a place where they "had to raise their voice to be heard" (Phase I; in Phase II "raise their voice" was replaced by "shout"). Figure 1 shows that the proportion of people who answered "Yes" to this question increases steadily until the age of 50-59 where the percentage falls off gradually, possibly due to differential mortality. Fewer people responded "Yes" to the question that included "shout", and fewer women than men responded positively. There was also a strong trend for a higher proportion of those in manual occupations to respond "Yes". The 1654 people in the clinic samples were assessed according to the standard protocol for noise immission, under three separate types of exposure; occupational, gunfire, and social. This Noise Immission Rating scale (NIR) was devised at the Institute of Hearing Research, by Dr Ross Coles and Dr Mark Lutman.

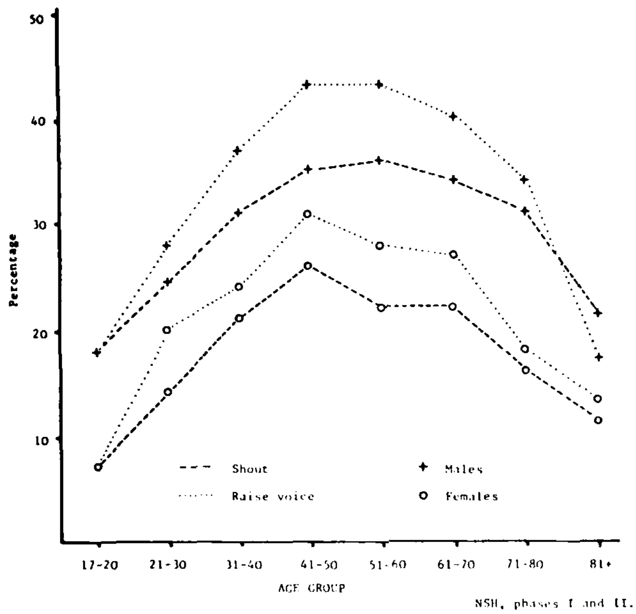

Fig. 1. The percentage of people who had worked for more than 6 months where it was so noisy that they had to raise their voice (phase 1) or shout (phase 2) to be heard.

The NIR encompasses both duration and levels of unprotected noise exposure. A rating of 1 for occupational noise immission is equivalent to 82-91 dBA for an average working week over a 40 year period. For the same period, rating 2 corresponds to 92-101 dBA, rating 3 to 102-111 dBA, rating 4 to 112+ dBA. The gunfire noise immission rating takes into account many different types of gunfire exposure, and reduces them as far as possible to a common metric which is essentially a logarithmic scale. Zero on the gunfire noise immission rating corresponds to unprotected exposure with no more than 10 service rifle shots fired. The social noise immission rating can be interpreted as for the occupational noise immission rating on a scale of time multiplied by dB equivalent levels.

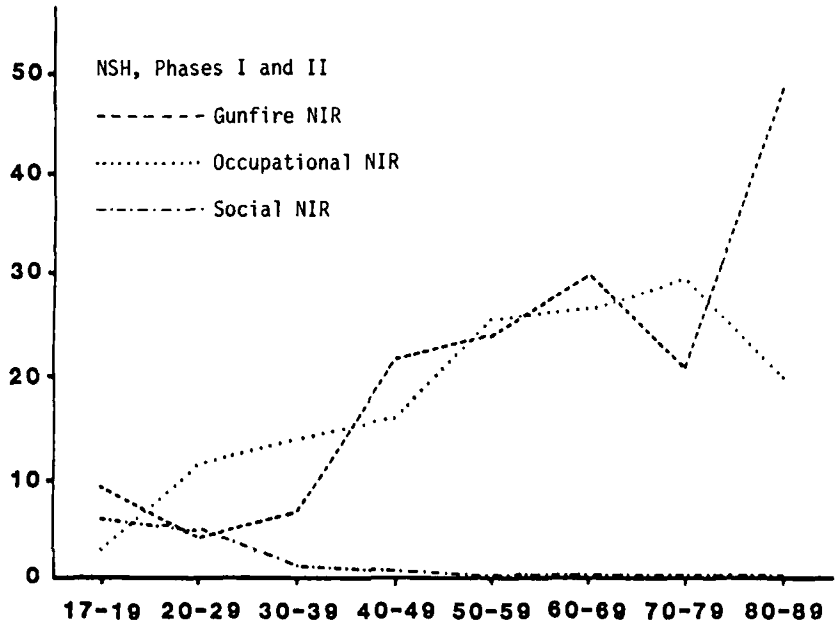

Fig. 2. Percentage of people with occupational, gunfire and social NIR greater than zero, in eight age groups. NSH Phase 1 and 2.

Table 2 shows the distribution of occupational, gunfire and social NIR with socioeconomic group. There is an extremely large variation in occupational NIR with socioeconomic group, and a much smaller variation, though significant ($p < 0.02$) in gunfire NIR with socioeconomic group. The sex effect is more uniform across noise type: for occupational NIR, 31% of men may be considered to have significant noise immission ratings, compared with 10% for women. For gunfire NIR, 38.6% of men had significant NIR but only 1.5% of women. (For social NIR the numbers were too small to allow any variation of socioeconomic group or sex to be assessed).

Table 1 shows the distribution of obtained NIR values. There is a very large sex difference in noise immission ratings. If we compare those having a zero rating for occupational, gunfire, and social noise exposure with those having a score of 1 or more on any of the scales, then 12% of women and 55% of men have a significant noise history.

NOISE TYPE	OCCUPATIONAL		GUNFIRE		SOCIAL	
SEX	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE
NIR 0	90.0	68.8	98.5	61.3	98.2	98.9
1	8.9	20.7	0.4	7.5	1.8	1.0
2	0.8	8.0	0.7	13.7		0.1
3	0.3	2.4	0.3	12.8		
4	0.0	0.1	0.2	4.5		

Table 1. The percentage of people in each noise immission rating (NIR) category as a function of type of noise and sex. NSH Phases 1 and 2.

Figure 2 shows the cross-sectional distribution of occupational, gunfire and social noise immission ratings with age. There is a trend for occupational and gunfire NIRs to increase with age, but for social NIR to decrease with age. As the NIR inevitably includes an age component one would expect some increase. However there is good reason to suspect strong cohort effects. The median age of our sample was 50; below that age the proportion of people with occupational and gunfire noise exposure is lower due to industrial changes and the discontinuation of general military service in the UK in the 1950s. The high proportions of gunfire noise exposure in the 80-89 and 60-69 age groups indicate the cohorts most affected by World Wars I and II respectively.

		Noise Overall	Type Occ.	Gunfire	Social
SEG I	Professional	12.4	2.8	11.9	0.3
II	Intermediate	24.0	8.2	18.6	1.3
IIIN	Skilled non-manual	20.1	9.7	13.0	2.6
IIIM	Skilled manual	39.9	29.3	21.7	1.2
IV	Partly skilled	42.6	32.8	16.6	0.3
V	Unskilled	28.0	19.7	13.1	0.0
NC	No category	16.8	1.2	16.8	0.0

Table 2. Percentage of people with an NIR greater than zero for each OPCS socioeconomic group.

From the public health point of view three points emerge. Firstly, on the positive side, the decrease in occupational and gunfire noise exposure in recent years is not outweighed by the increase in social noise exposure. Secondly, Table 2 shows that there is little overlap of exposure to the different noise types. An exception occurs within SEG IIIM where 11% were exposed both to significant gunfire and occupational noise, and, to a lesser extent within SEG IV. Thirdly, age, socioeconomic group and sex are all fairly good predictors of NIR. This will cause problems of collinearity in multiple regression analyses which attempt to correct for these other factors while regarding NIR as an independent variable and hearing level as the dependent variable. These statistical problems are compounded by the fact that unless there is high sampling of a stratum formed for high occupational NIR, then a fairly low proportion of people in any subject pool will have a material NIR.

2) *Tinnitus.* Tinnitus was assessed in a clinical interview. The results reported here are for Phase I only, although a similar pattern occurs for Phase II. There was a significant effect of occupational NIR, for both men and women (χ^2=12.3 for women, χ^2=8.37 for men, $p < 0.1$). The overall effect of NIR was attenuated by a lack of significant exposures in several of the age and socioeconomic groups. The largest effect of NIR

on tinnitus was in socioeconomic groups IIIM and IIIN combined, in the 40-60 age bracket, congruent with the large numbers receiving high noise exposures in these strata. Here the prevalence of reported tinnitus was 21% for zero NIR, 41% for NIR of 1, and 60% for NIR of 2 or more (χ^2=16.9, $p < 0.002$). Overall, there was no significant effect of gunfire NIR.

3) *Air-bone Gap.* In Phases I and II of the National Study of Hearing bone conduction thresholds were measured at 0.5, 1.0, and 2.0 kHz. The difference between the threshold for air conduction and bone conduction was taken as a dependent variable in a multiple regression with age, sex, socioeconomic group, and noise exposure as independent variables. No factors emerged that were consistent over phase of the study or test frequency; this confirmed the absence of an age trend in the conductive component. However tinnitus was associated with a larger air-bone gap; clinically, tinnitus is known to occur in many conductive as well as sensorineural conditions.

4) *Hearing Levels.* The analysis of determinants of hearing threshold levels was necessarily complex. The first stage involved linear regressions of the main likely factors on the raw better ear thresholds at each frequency and on the differences between ears. However a significant advantage in both homogeneity of variance, and in proportion of variance explained was found if a log transformation of the threshold measurement was made, adding 20 to avoid zero values in 'normals'. Although effects of age and other factors emerged there was no overall effect on the better ear threshold of occupational NIR or of the screening questionnaire noise history questions nor did significant interactions with either variable emerge consistently over the two phases.

I will return later to possible reasons for this.

In the second stage of the analyses principal components were extracted from either the raw data or the transformed log values for the 8 test frequencies on the better ear. The components extracted were essentially the same for Phase I and Phase II and for the two measures used. The first component was a straightforward average across frequency of the hearing thresholds, the second component was an audiogram slope measure, and the third component was an estimate of the quadratic trend between low- and high-frequency thresholds, i.e. steepening of this slope towards high frequencies. In all, the principal components accounted for on average 92% of the variation in the raw data. These components offer a rational way of totalling measures across frequency for reliability, while preserving aspects of audiogram shape that may relate specifically to aetiology or associated variables. Table 3 presents the significant parameters for the regression on the log of the first component in Phase II. Age, sex, socioeconomic group, tinnitus, noise history (questionnaire), occupational NIR and ACORN classification are the independent variables. ACORN is a classification of housing type which provides a second socioeconomic factor to supplement occupation. Interactions up to first order were tested. Socioeconomic group, ACORN and NIR were reduced to dichotomies in order to obtain enough subjects for the analysis. This regression accounts for 53% of the variation in the first principal component, a satisfactorily high percentage for epidemiological research. Neither noise measure was significant, nor did either significantly affect the second and third principal components (which in a sense carry a high-frequency weighting), despite the traditional association of noise exposure with high-frequency loss.

Factor	Estimate	Standard error	$F_{1,802}$
Age-linear	.0068	.0017	15.8
Age-quadratic	.0065	.0030	4.7
Sex	-.1492	.0496	9.0
Socioeconomic group	.0825	.0187	19.5
ACORN	-.0776	.0186	17.3
Tinnitus	-.1149	.0806	2.0
Noise (questionnaire)	.0355	.0232	2.3
NIR	.0426	.0257	2.7
Sex by age	.0047	.0010	22.1
Tinnitus by age	.0049	.0016	9.9

Table 3. Parameters of regression analysis on the log of the first principal component of the hearing thresholds, better ear, NSH Phase II.

Y variate = $\ln (160+t_{250}+ \ . \ . +t_{8000})$
where t_{250} = threshold at 250 Hz in better ear, etc.

The results presented in Table 3 are typical of many of the analyses that we have conducted so far. Firstly they indicate that the age effect is greater in men than in women. This will be pursued in the next analysis. Secondly the null result for NIR should be considered in the context of the interdependence of age, sex, socioeconomic group, housing type and the two measures of noise history. Also the low prevalence of significant noise history, weakens the power of regression analysis to detect noise effects in the populations we sampled. We hope to increase this power in Phase III by stratifying the clinic sample on a measure of noise immission. Meanwhile, the result can be interpreted in two ways. At the practical level, one can consider that socioeconomic and demographic factors are a better indicator of actual noise immission than either of the verbal noise history measures. Alternatively, the effect of noise immission on hearing levels in the population may not be as great as the effect of other causes that happen also to align with important socio-

economic and demographic variables, e.g. visible ear disease, drug ingestion, cardiovascular health, diet and even ability or willingness to perform audiometry.

5) *Hearing levels separated by sex.* In the light of the interaction of age and sex, separate analyses were carried out on the better ear hearing threshold data from Phase II, for 496 women and 398 men. All effects mentioned were significant at $p < .01$. For the women, there were significant linear and quadratic effects of age (i.e. accelerating hearing loss), also interactions of age with tinnitus and age with noise. There were also significant main effects of socioeconomic group and ACORN housing type confirming the value of this second socioeconomic measure. There was no effect of either measure of noise history. However the following first order interactions were significant; socioeconomic group by NIR, socioeconomic group by noise reported at the screening questionnaire, and ACORN housing type by NIR. These interactions suggest that the effect on hearing from a given level of reported noise exposure is greater in lower socioeconomic groups.

In a similar analysis of the male data there were linear effects of age and interactions of age with i) tinnitus and ii) the report of noise exposure in the screening questionnaire. Again there were main effects for socioeconomic group and ACORN housing type.

CONCLUSIONS

Because of the high collinearity between noise immission ratings and age, sex and socioeconomic group, and because of the low population prevalence of substantial noise immission ratings, it has so far proved to be very difficult to associate a noise history with increased risk of measured hearing impairment in the general population. We do not of

course deny that high noise levels can cause hearing loss and should be controlled. Rather our population studies suggest that further noise control and hearing conservation measures, might make only a small impact on general population prevalences of hearing impairment. More generally, our studies provide a necessary framework for assessing the influence of noise or any other noxious factor on hearing. Age and sex should be taken into account as covariates, also socioeconomic group and housing type. Perhaps most importantly whether there is any history or presence of tinnitus should be included as a stratification variable in noise studies, as significant noise effects are more readily shown for tinnitus than for hearing levels.

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ACKNOWLEDGEMENTS

My thanks go to Nicholas Longford for significant assistance with analyses, to Heather Fortnum for assistance with presentation of the manuscript, also to Mark Haggard, Ross Coles, and Stephen Holdoway for comments; to the staff in the Cardiff, Glasgow, Nottingham and Southampton outstations of the Institute who investigated and tested the subjects; and to all the subjects who gave time to be tested.

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PRECISION AUDIOMETRY AND THE EFFECTIVENESS OF HEARING CONSERVATION PROGRAMS

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INTRODUCTION

Very few investigations have been made into the effectiveness of a hearing conservation program based on a reduction in the deterioration in hearing caused by noise, after hearing threshold changes due to presbyacusis have been considered. The crucial factor in such an investigation is the accuracy with which the individual hearing threshold level can be recorded. An increase in the accuracy means that a noise-induced hearing loss may be revealed at an earlier stage or after a smaller reduction in hearing capacity. This in its turn means that the effectiveness of the hearing conservation program can be checked at an early stage.

MATERIAL AND METHODS

Uncertainties

It has been pointed out that one of the main factors contributing to the uncertainty in HTL measurements is the positioning of the earphones (Erlandsson et al., 1980). It is quite obvious that a more accurate way of defining the earphone position relative to the eardrum would be of great help in reducing the uncertainties in the HTL measurements.
In order to overcome this problem, an earphone fitted with an ear speculum has been designed, Fig. 1. This enables the earphones to be placed so that the sound impinges directly on the eardrum and also allows for accurate replacement of the earphones. The specula and earphones sitting on a special

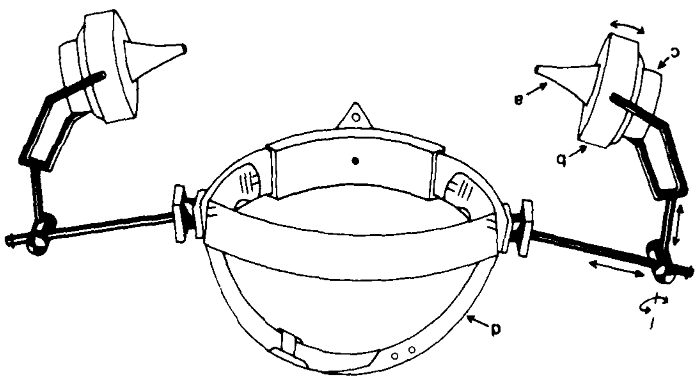

Fig. 1 Diagram of the headset showing the specula and the adaptors. a=specula, b=adaptors, c=earphones and d=plastic frame.

headset which is securely positioned on the subejt's head, may be moved in all directions relative to the head. Measurements of the absolute hearing threshold are of course affected by the presence of the speculum, but this is of no consequence in a comparative investigation where the same apparatus is used on every occasion. In this case, the errors in HTL measure-are only 1.6 to 3.3 dB within the frequency range 2 to 8 kHz (see table I). Convertion of HTL values obtained by cushions to specula values or vice versa can be made (Ivarsson et al., 1983). However, a comparison is made more difficult and the errorsare not reduced owing to the uncertainty involved in the renormalization of the speculum data.

Table I The mean SD's obtained using different audiometric techniques.

Method	SD at different frequeincies (dB)									
	frequency (kHz)									
	0.5	1	2	3	4	5	6	7	8	mean 2-8
Fixed Békésy with cushions	3.1	3.2	4.2	3.8	4.4	5.5	4.9	5.4	6.5	3.3
Fixed Békésy with speculum	3.1	3.0	2.5	2.6	1.9	1.9	2.8	2.5	3.3	1.6
Sweep Békésy with cushions	3.2	2.4	3.5	2.8	3.3	3.4	3.4	3.4	4.2	2.4
Sweep Békésy with speculum	4.3	3.4	2.9	3.0	2.9	1.6	2.0	2.1	2.2	1.6

Types of audiometry

Two types of audiometers have been used, an ordinary Békésy sweep-frequency audiometer, type Demlar 120, and a computerized Békésy audiometer (Ivarsson et al., 1980). Both audiometers were fitted with TDH-49 earphones, and in the first place with MX-41/AR cushions. The system was calibrated in the continuous tone mode with a Bruel & Kjaer artificial ear, 6 cm^3 coupler, a 1" microphone, a preamplifier and a frequency spectrometer. The reference values for the hearing thresholds were adjusted to ISO R389 (1975).

Noise dose measurements

Noise dose measurements were carried out in 1977, 1979 and 1983 with ear-borne dosimeters. During 1977 and 1979 Crafon dosimeters recording, on photographic film, the total time preset levels (85, 95, 105 and 115 dB(A)) were exceeded were used (Erlandsson et al., 1976). For the 1983 measurements another device was used incorporating a microprocessor (Håkanson et al., 1983). From both dosimeters the noise dose, or L_{eq} values, is calculated using a slightly modified technique as has been described in Erlandsson et al.(1980b).

Subjects

The subjects of this investigation belonged to the workforce of the assembly hall and boiler shop of a shipyard. At the beginning of the investigation in 1977, 67 and 55 males participated from the assembly hall and boiler shop respectively, and seven years later 33 and 34 of the original participants were left in their respective places of work and still taking part in the investigation.
An otological examination, combined with a questionaire regarding the subject's personal history, was carried out in conjunction with the audiometric test. Ears were defined as "normal" when they complied with standard requirements as given, for example, by Burns & Robinson (1970).

Test procedure

The audiomteric tests were carried out in the sound-isolated booth of a small mobile acoustic laboratory, and the background noise levels conformed with specifications given in ANSI S3.1,1977. For both types of audiometers the test was started at 0.25 kHz and the frequency sweep continued up to 8 kHz. Immediately afterwards the seep was reversed and swept back to 0.25 kHz. The attenuation rate was 2.5 dB/s with pulsed tone presentation and the duration of the sweep was 400 s. The hearing threshold level was obtained both for the upward and downward frequency sweeps by taking the mean value of the upper and lower peaks of the trace. The mean of these two values was the calculated. All hearing tests were made at least 16 hours after the subjects had been exposed to occupational noise. The middle ear pressure of all subjects was checked to be less than 5 cm H_2O before the audiometric test (Erlandsson et al., 1980c).

RESULTS

One of the crucial points to be considered when conclusions are to be drawn from HTL measurements is the uncertianty in the individual HTL measurements.

The uncertainties in the HTL measurements were assessed from five test-retest measurements on 20 ears. The results of this study showed that a good reliability could be obtained if the mean HTL ($HTL_{\overline{2-8}}$) for each integer frequency from 2 to 8 kHz was calculated (Ivarsson et al., 1983). From the pooled estimate of the standard deviation of the mean HTL's for the 2-8 kHz region the uncertainty in $HTL_{\overline{2-8}}$ was found to be $\pm$ 2.4 dB using sweep-frequency Békésy audiometry with cushions, and $\pm$ 1.6 dB for the corresponding measurement made using the same audiometric technique with the specula. This means that the mean standard deviation of the yearly change in $HTL_{\overline{2-8}}$ ($\Delta HTL_{\overline{2-8}}$) for two measurements with a period of one year in between is $SD.\sqrt{2}$, for 3 measurements is $SD/\sqrt{2}$ and for 4 measurements is $SD/\sqrt{5}$ and so on.

In the present work the measurements were started in 1977 and after 7 years 67 subjects were left (34 in the boiler shop and 33 in the assembly hall). Of these, all except 2 said that they used earplugs or earmuffs.

The change in measurement technique in 1981 from cushions to specula caused a reduction in the uncertainties in the HTL measurements. Fig. 2 shows data for the seven yearly HTL measurements on one person. Although this figure only shows the HTL's of one single person, the change in the slope of hearing deterioration is symptomatic for the whole material which shows a significant reduction in the rate of HTL change on the 95% confidence level, both for the boiler shop and assembly hall. Testing on the same confidence level shows that there are 20 ears (33%) in the boiler shop group and 25 ears (30%) in the assembly hall group showing a significant change in $\Delta HTL_{\overline{2-8}}$ between the two periods 1977-80 and 1981-83.

DISCUSSION

The main question under discussion are why the periods 1977-80 and 1981-83 are of such interest and what could have happened during 1980 and 1981 to

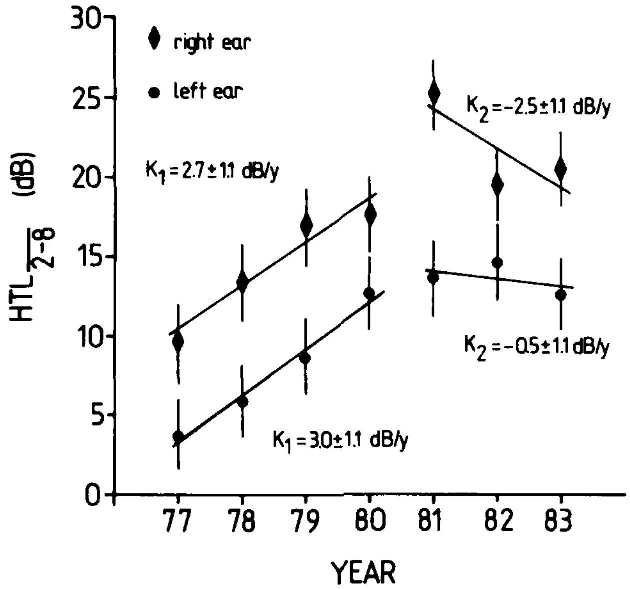

Fig.2 An example of the calculation of the ΔHTL. The HTL data are plotted against time and fitted by straight lines, the gradients of which gives the $\Delta HTL_{\overline{2-8}}$.

change the trend in hearing deterioration.

In 1981 there was a change in the audiometric technique from cushions to specula. Although this brings about a change in the HTL values which varies with frequency this may be corrected for (Ivarsson et al., 1983). The data have been studied and it was found that the introduction of the specula did not cause a systematic lowering or increase in the HTL's.

The place of work under investigation (a shipyard) has a long tradition in using hearing protection. Different kinds of earplugs and earmuffs have been used since about 1960, and only a few percent of the workers state that they never used hearing protection. All others declare that they use som form of protection. In spite of these declarations, the first years of

audiometric measurements showed that several workers suffered significant deterioration in their hearing ability in the 2-8 kHz range. Therefore an extensive hearing program was introduced in 1979 aimed at improving the use of hearing protection. Nevertheless, in 1980, after four years of measurements 25% of the ears in the boiler shop and 11% of the ears in the assembly hall showed a significant deterioration in hearing at the 95% confidence level after presbyacusis had been taken into consideration (Erlandsson et al., 1983a). Individual information was given to these people and they were recommended to used both earplugs and earmuffs.

We would like to think that the lessening of hearing deterioration exhibited during the last 2 years is due to more conciencious use of hearing protection. This suggestion is strengthened by the fact that the individual noise doses, measured at the ear, have been quite constant during the measurement period. See table II.

Table II Noise dose measured at the ear in the boiler shop and assembly hall.

Area	1977	1979	1983
Boiler shop	L_{eq} = 91.0 dB(A) n = 213 SD = 4.1	L_{eq} = 91.3 dB(A) n = 183 SD = 4.2	L_{eq} = 90.4 dB(A) n = 42 SD = 3.9
Assembly hall	L_{eq} = 88.6 dB(A) n = 200 SD = 5.5	L_{eq} = 89.7 dB(A) n = 69 SD = 4.9	---

It has been shown that relatively short periods without hearing protection can cause a considerable reduction in their effectiveness, (Else, 1973; Carmy & Coles, 1975). Recent simultaneous noise dose measurements both inside and outside earmuffs show that the noise dose, expressed as the L_{eq} value is reduced only by about 10 dB, see fig. 3, (Erlandsson et al., 1983b)

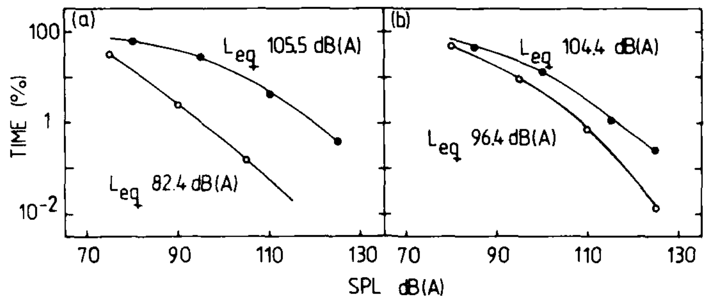

Fig. 3 Fraction of time over preset sound pressure levels measured inside (o) and outside (•) earmuffs, a) carefully controlled conditions and b) normal workshop conditions.

This value shows that earmuffs with a high laboratory attenuation produced a much smaller reduction in noise in the field than expected.

During the last three years there is even a tendency for some persons towards a lowering of hearing threshold levels. This may be due to more conciencious use of hearing protection during working hours, and a greater awarness of noise even during leisure time, thus leading to a reduced temporary threshold shift (TTS). Although recovery from this TTS may not be complete the next morning, the residual TTS would be much smaller giving rise to an improved HTL compared with that in previous years.

CONCLUSIONS

Our research has shown that knowledge of the accuracy with which individual hearing thresholds can be recorded gives the opportunity to define, with a particular certainty, a minimum yearly change in hearing threshold. This minimum yearly change can be further reduced by using a new device, the ear speculum, in the audiometric measurements, and also by serial audiometry with intervals of one year.

Conclusions regarding the effectiveness of hearing conservation programs can thus be drawn through observations of the change in ΔHTL (the yearly

rate of change in hearing threshold at such a low level that they only to a minor extent affect the hearing situation of the person taking part in the program.

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EARLY DETECTION OF HEARING DAMAGE BY HIGH-TONE AUDIOMETRY.

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INTRODUCTION

The hearing frequency of the human ear extends from 16 Hz to 2o ooo Hz. Generally we examine frequencies from 125 Hz to 8 ooo Hz.

Though, the most important speech frequencies are to be found only between 5oo Hz to 3 ooo Hz, the question still remains whether the values of high-tone audiometric examinations between 8 and 2o kHz may give important additional informations not obtainable by standard audiometric procedures.

This problem is not quite recent. First Rosen /1964,1971/, Harris /1967/, Northern /1972/ et al., to mention the best known names, later Beiter /1976/, Böhme /1976/ as well as Dieroff /1976,1982/ and his coworkers have studied hearing above the frequency of 8 ooo Hz.

Overcoming the initial technical difficulties,

studies showed that examinations of hearing at high frequencies were very valuable in the diagnosis of hearing impairment. Sensorineural hearing damage began on high frequencies gradually involved the lower frequencies later and caused hardness of hearing and difficulties in understanding of speech.

These informations and our previous experiences /Ribári et al. 1981.a,b, 1982/ moved us to use high-tone audiometry for the early detection of noise deafness and sensorineural hearing damage caused by ototoxic drugs.

MATERIAL AND METHODS

Examinations were done by a high-tone audiometer constructed at our clinic. We used HOKUTON 5o PT 54H type high-tone transmitter secured at 7o mm from the external auditory meatus. This measuring system was calibrated by the help of digital frequency meter /TR 5258/D oo9/, sound-level meter /Brüel-Kjaer 22o3/, and by condenser microphone /Brüel-Kjaer 4134/ measuring between 2o to 2o ooo Hz.

Examined subjects may be divided into the following groups:

1./ High-tone hearing threshold was determined on 8 subjects /3 female, 5 male/ 2o years of age who were found having normal hearing by traditional audiometric examinations. Examinations were done on 16 ears at 6-6 different times, unrelated to each other, for the purpose of reproducing the hearing threshold measured by the system.

2./ High-tone hearing threshold was determined by our system on 5o /18 f, 32 m/ healthy subjects who were considered having normal hearing. In each age group 1o-1o subjects were examined, altogether 1oo ears.

3./ We have examined the high-tone hearing thresholds of 5o male subjects who worked in sites where the wide-ranged irregular noise had levels from 1o5 to 115 dB A.

Exposure to noise was o, 4, 8, 16 years, in every age group 1o-1o subjects were examined.

4./ We have examined 4o young females with normal hearing who began to work in a textile factory. Their high-tone hearing was found normal. After the first year 7 employees out of the 4o had a hearing loss at 13-15 kHz, while hearing damage was not shown by conventional audiometry. Following closer examinations of the cases it became evident that the 7 employees did not wear any ear protection.

5./ Examinations were carried out on 14 patients / 6 f, 8 m / who were given Streptomycin for the treatment of tuberculosis. The patients were between the age of 3o to 4o years and their hearing was normal before the treatment, they had not worked in noise and had not received ototoxic drugs previously. We have done high-tone audiometric examinations before the beginning of the treatment, after two weeks, resp. following intake of 15, 3o and 4o gr of Streptomycin.

6./ We have examined 13 subjects with normal hearing between the age of 2o to 25 years who had Gentamycin B-SO_4 treatment. These patients had high-tone audiometric examinations before the beginning of the treatment and on every day under the treatment. In addition to the audiometric examinations we have done pharmacokinetic examinations. Also the level of Gentamycin concentration in blood was determined. Pure-tone audiometric examinations were done in every case by Peters AP-6 audiometer from 125 to 12 ooo Hz.

RESULTS

We have measured the hearing of subjects with high-tone audiometry who were otherwise found with normal hearing by standard audiometry and evaluated data. Up to 16 ooo Hz values of threshold levels are reproducible exactly, above this standard deviation may reach ± 1o dB. Subjects who belong to young age groups have very good reproducibility up to 16 ooo Hz and low standard deviation. High-tone hearing of older persons gradually decreases in accordance with literature / Fig. 1, 2./. High-tone audiometric results of subjects working in noise show that the mean threshold values on different

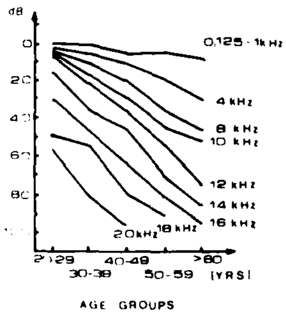

Fig.1 - Mean value of hearing thresholds by age groups of healthy subjects measured at different frequencies.

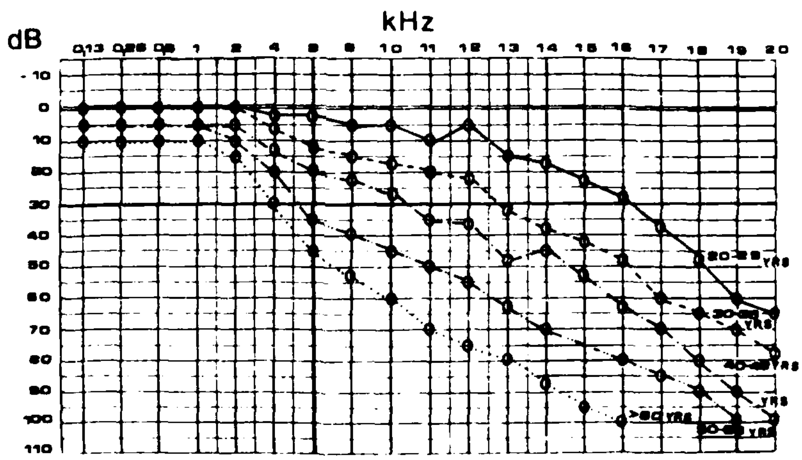

Fig.2 - Mean high-tone audiogram of subjects in different age groups. ———: group of 20-29 yrs, — — — : 30-39 yrs, —.—.—.: 40-49 yrs, —..—..— : 50-59 yrs, ... : above 60 yrs.

frequencies vary significantly. Hearing loss on high-tone appears much earlier than on the conventional audiogram / Fig. 3./.

According to the results of our examinations the decrease of the hearing of high-tone becomes more definite with the increase of exposure to noise, hearing

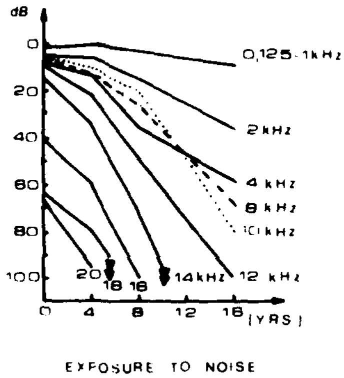

Fig. 3 - Mean values of hearing thresholds of workers in continuous noise measured at different frequencies in dependance to time of exposure to noise /⬇ values beyond measuring /.

damage shows earlier on frequencies between 15-16 000 Hz /Fig. 4./.

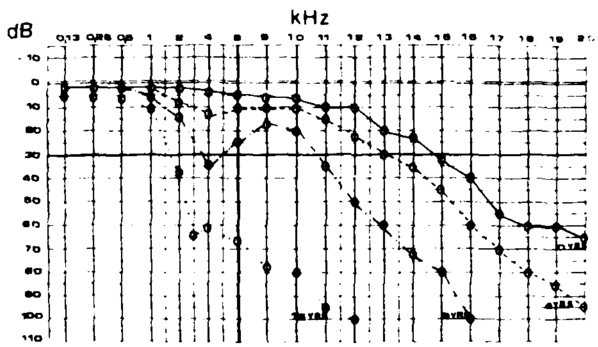

Fig. 4 - Mean high-tone audiogram of workers exposed to noise through 0 /———/, 4 /– – –/, 8 /–.–.–/, 16 /...../ years.

As a result of Streptomycin treatment a minimal hearing loss may be observed on a normal audiogram up to the frequency of 8 000 Hz, even following 30 to 40 gr of total dosages. Above the frequency of 8 000 Hz however hearing loss appears which is indicated early

by high-tone audiometry. After the discontinuance of the treatment the process of decreasing high-tone hearing stops /Fig. 5./.

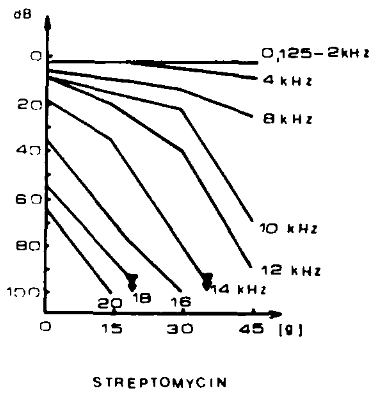

Fig.5 - Change of hearing threshold values measured at different frequencies in dependance of dosage of Streptomycin /↓ values beyond measuring /.

As an effect of the treatment by Gentamycin B-SO_4 hearing damage was found on high-tone only to a small extent, besides normal renal function. One patient had lasting 15 to 2o dB hearing damage above 1o ooo Hz, which was not detectible on normal audiogram. Two patients had reversible damage showing on 13-14 ooo Hz frequencies and at ten of the patients hearing damage was not registered. After the first and second month following the treatment there was not any change on normal audiograms: hearing loss on high-tone became normal at two of the patients and only one patient had lasting hearing loss on frequencies between 12-15 kHz.

DISCUSSION

By using the high-tone audiometer constructed at our clinic with the Hokuton high-tone transmitter reproducible measuring may be done.

In our opinion standardization of measuring is of great importance and to comply with it is necessary. The change of high-tone hearing may be valued correctly only by the measuring of high-tone of every subject examined before the exposure to noise or before the beginning of pharmaceutical treatment. There is a great difference between values of high-tone hearing of individuals. Normal values cannot be set for high-tone hearing. Results of examinations may only be compared to one's own starting high-tone audiogram serving as reference value.

As for the effect of acoustic exposure just before or at the same time with the appearance of the characteristic dip on 4-6 000 Hz high-tone hearing loss may be shown well, in the same way TTS may be measured very well and conclusion may be drawn on the susceptibility of the individual to noise.

As the effect of Streptomycin and Gentamycin high-tone hearing loss may be shown early too. The damaging effect of ototoxic drugs may be revealed with high-tone audiometry much earlier than by conventional audiometric measuring.

In our view high-tone audiometry may be used well

for early detection of hearing damage caused by excessive noise or by ototoxic drugs as well as for revealing the susceptibility to noise.

* Supported by grant from the Hungarian Ministry of Health under project No. 0,2/4-27/461.

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ON PREDICTION OF PTS BY MEANS OF PSYCHOACOUSTIC INVESTIGATIONS AS WELL AS REGISTRATION OF COCHLEAR EMISSIONS.

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1. INTRODUCTION

To reduce the incidence of noise-induced hearing loss in the population one can make use of the fact that the susceptibility for the condition is subject to considerable interindividual variations. In a given population this susceptibility shows an approximately normal distribution with almost no tendency to develop hearing loss at one end of the curve. Consequently, the incidence of noise-induced hearing loss in a population would be almost nil, if only persons reflected by this part of the curve would be hired for noise-related jobs. The rate of noise-induced hearing loss to be expected in a population will, using an effective test for prediction, primarily depend on the ratio between the applicants for apprenticeship and the vacancies available. If much few people are needed than actually apply for a noise related job it is possible to single out those who are included in the low-risk end of the normal distribution curve for noise-induced hearing loss. However, such a selection criterion would only be useful if one can make a choice from a sufficiently large number of persons and if one is not forced to hire all applicants.

There have been many attempts at predicting PTS. Most of them were based on TTS experiments. A pertinent review was

published by Dieroff (1963) and Ward (1968). A closer examination of these experiments will show that many examiners used inadequate sound energies for producing experimental TTS. This may be explained by the lack of knowledge about the inaccuracy of audiometric tests at the time at which the experiments were done. In addition, long-term follow-ups were not available. Peyser, for instance, never tested the selection method proposed by him in a predictive study. He simply recommended its use assuming that there must be a relation between TTS and susequently acquired PTS.
The failure of these efforts (Luts 1981), many of which were not compatible with modern scientific precepts (e.g. Peyser 1940 and Peyser 1952), does by no means imply that the search for a method of predicting PTS on the basis of TTS experiments would be futile (Ward 1973).

2. THE FREQUENCY CHARACTERISTICS OF TTS

2.1.1. Before 1975 it was thought that there was only a single TTS presenting as a relatively marked dip which reaches its maximum at 1/2 to 1 octave above the exposure frequency and has been extensively studied. Unlike PTS, this dip depends on the exposure frequency.

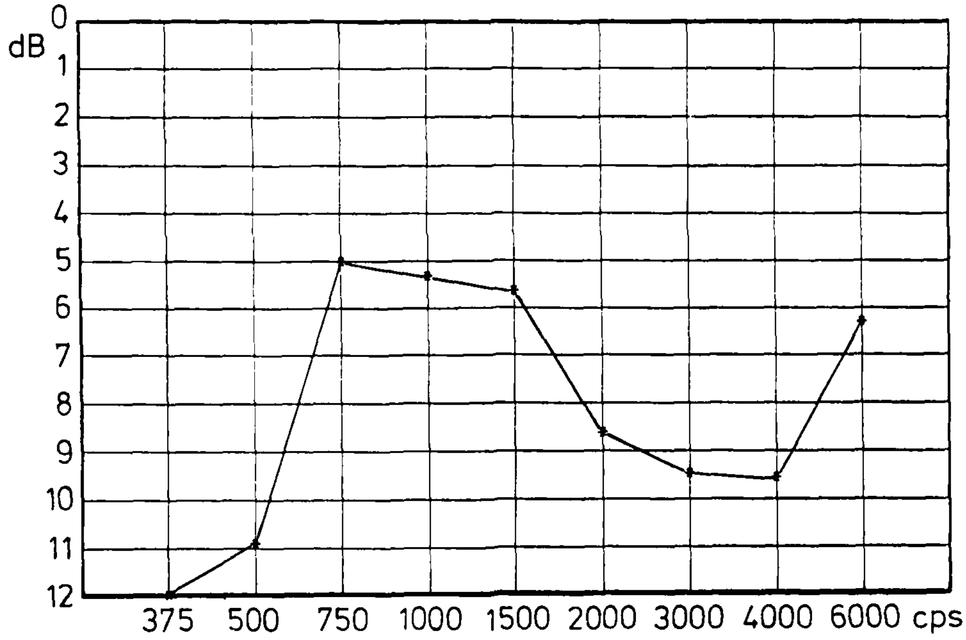
2.1.2. There is, however, a second TTS at 4000 Hz range (Fig.1, Fritze 1975). This second dip is entirely isolated from the well-known first deflection and, irrespective of the exposure frequency, consistently occurs in the PTS frequency range (Fritze 1980). In appearance, it is similar to a minor PTS but, as it is a TTS, it is fully reversible. Like the first dip, it shows considerable intersubject variation and its amplitude does not correlate with that of the first dip.

2.1.3. Recent studies (Bartsch, Brückner, Dieroff and Fritze 1981) produced evidence of another TTS beyond 10 kHz. In preliminary investigations this was equally found to show considerable intersubject variation, not only in amplitude but also in the frequency range.

2.2. THE SECOND TTS IN THE HIGH-TONE RANGE

There are 3 reports in the literature which offer indirect evidence of a TTS in the PTS range after low-tone exposure:

2.2.1. Using industrial noise of different components for exposure, Van Leeuwen (1955), like Van Dishoeck(1966), interpreted the curves (Fig. 2) obtained as the high-tone range, i.e. the PTS range without accentuation. In the author's



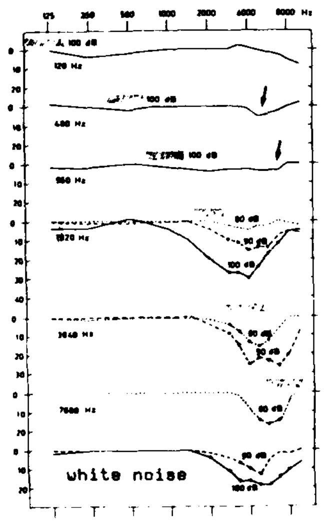


Fig. 1: The two TTS dips in a Békésy audiogram recorded at 375 Hz to 6 kHz. The exposure had been a sinus-tone of 250 Hz 120 dBA, 5 min.; the preexposure values are subtracted. To compensate regression half of the subject were examined at ascending frequencies, the other half at descending frequencies (n=16). The isolated dip in the PTS range is clearly seen.

Fig. 2: TTS after exposure to multiple-component industrial noise (5 minutes). While Van Leeuwen and Van Dishoeck did not find the high-ton range of these curves to be accentuated, the author feels there is evidence of accentuation in the second and third curve. Similarly, the dip in curves 6 and 7 cannot be explained in terms of a frequency-dependent TTS. (From Van Dishoeck 1966, arrows by the author).

view these TTS curves do, however, show some accentuation of the PTS range.

2.2.2. Dieroff and Beck (1966) exposed rabbits to noise produced by sanders which essentially consisted of low-frequency tonal components. Aside from a damage of the hair cells about 1 octave above the frequency range, they found an equally reversible damage in the PTS range.

2.2.3. Kohllöffel (1983) could show a vibration (distinct from that which causes hearing sensation) in the PTS range.

2.3.1. METHODS FOR IDENTIFYING THE SECOND TTS IN THE PTS RANGE

2.3.1. Sound exposure

Exposure to sufficiently high energies (within the limits of the maximally permissible daily exposure) will readily demonstrate the second TTS in psycho-acoustic experiments. The exposure frequency should, however, be low enough so that the 2 dips can clearly be separated from one another. Two factors prompted the author to choose a closed system for his sound exposure experiments:(1) In such a system the intensity can be more accurately defined than in an open sound field; (2) at the intensities used the low frequencies are quite unpleasant to the subjects in an open system. In most experiments a Peerless KO4o MRF transducer served as loudspeaker. While the ratio between the duration and the intensity of exposure is determined by the loudspeaker used with the distortion being dependent on the intensity, the desired efficiency of the test procedure requires that exposures should not be continued for too long. At the intensities used (between 108 and 128 dB SPL) the distortion in the closed system is well within the tolerable range (Fig.3): At an exposure time of about 10 min. the first 2 harmonics at an intensity of about 70 dB are unlikely to contribute appreciably to a TTS.

2.3.2. Recording techniques

2.3.2.1. Initially (Fritze 1975) a sweep-frequency Békésy-audiogram with frequencies between 3.5 and 5 kHZ was used (Fig.4). It provided for 4 pre-exposure and 5 post-exposure examinations (the latter within 10 minutes). The threshold shift,the reduction in writing amplitude and the regression of the two phenomena can clearly be seen.

2.3.2.2. In another experimental design (Fig.5) Békésy audiograms were recorded at a constant frequency of 4 kHz (Fritze 1978). This protocol is particularly useful for routine examinations. Sofar the author has used a frequency of 4 kHz throughout. Extensive studies would be needed to find the frequency which is optimally suited for the PTS range.

2.3.2.3. Yet another experimental design (Fig. 1) involved sweep-frequency Békésy audiometry between 375 Hz and 6 kHz (Fritze 1978). This clearly shows the 2 distinct

dips which, as mentioned, are unrelated in terms of their amplitudes.

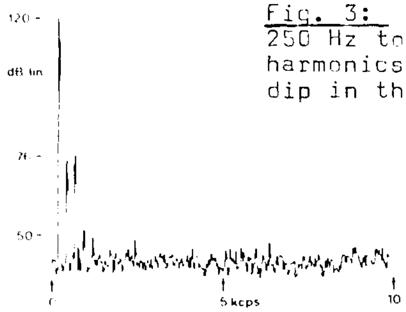


Fig. 3: Fourier transformation of the 250 Hz tone. There is no evidence of any harmonics which might produce a second TTS dip in the PTS range.

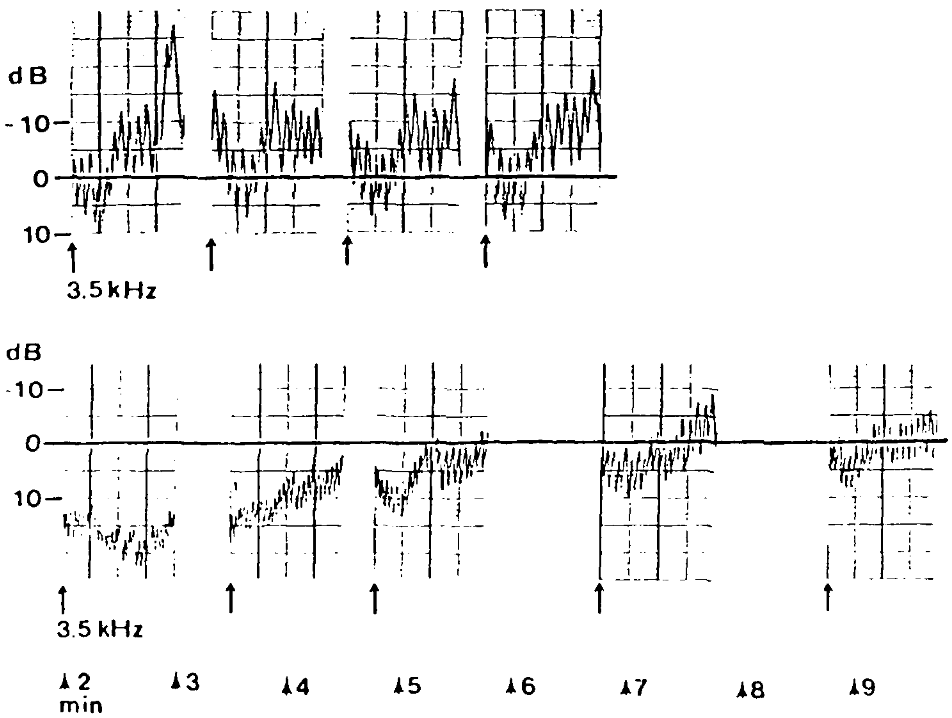


Fig. 4: Sweep-frequency Békésy audiogram at 3.5 kHz to 5 kHz recorded 4 times preexposure and 5 times between the 2nd and the 10th minutes post exposure (250 Hz sinustone. 100 dBA, 20 min.). The TTS, the reduction in writing amplitude and the regression of the 2 parameters are clearly seen.

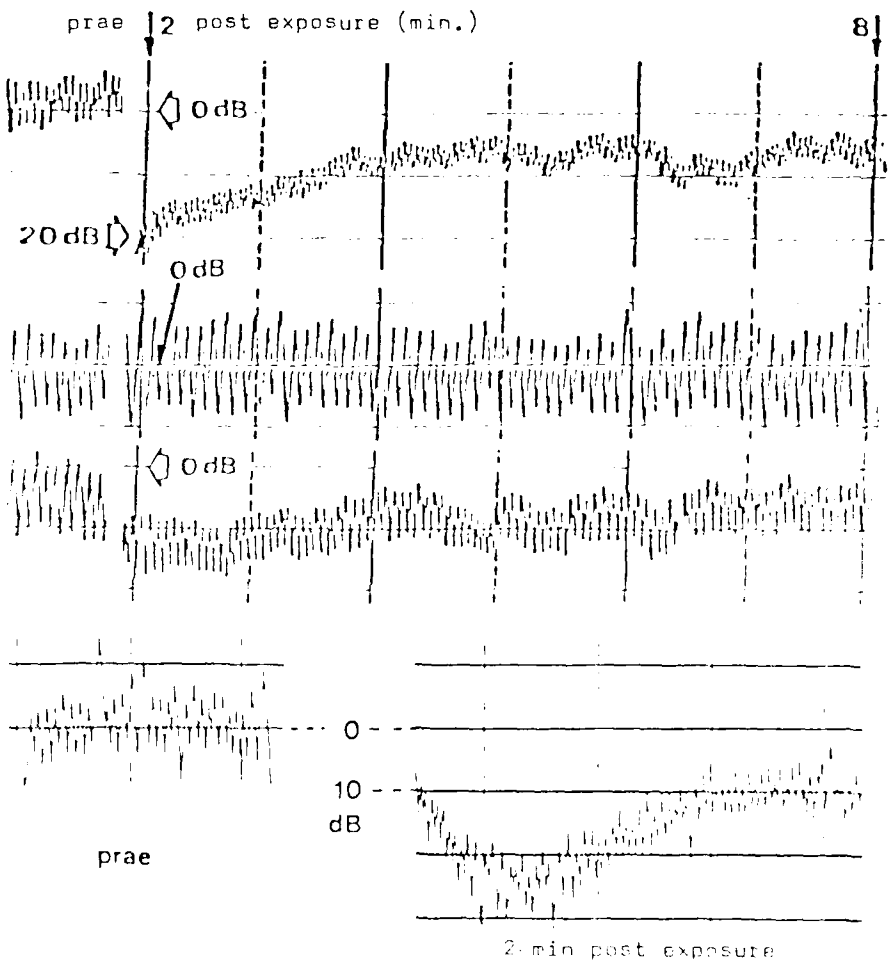


Fig. 5: For routine testing a constant-frequency recording technique is most useful. In the example shown the frequency was 4 kHz. Before exposure Békésy audiogram was continued to the point of obtaining a more or less stable curve. For exposure a 120 dBA, 250 Hz sinus tone was administered for 10 min. The upper 3 curves clearly show to interindividual variability of the dip in the TTS range. The 4th trace gives the growth of the TTS up to the second minute repeatedly reported in the literature for the first dip.

2.4. PREDICTIVE STUDY

In 1978 the author had an opportunity to examine apprentices in a metal-working plant at the beginning of their apprentice-ship for the dip in the high-tone range after low-tone exposure (Fritze 1978). The protocol used is shown in Fig. 5. In the examinations the mean TTS_2 (n= 42) at 4 kHz was 15.25 dB with a variation of 8.10. At 8 minutes post exposure the threshold shift had regressed to 7.8 dB.

The writing amplitude in the Békésy audiograms at 2 minutes had diminished to 0.83 with a variation of 0.22. At 8 minutes it had virtually returned to pre-exposure values. Twentytwo subjects were re-examined after apprenticeships of 3 years. At that time a mean PTS of 6.9 dB with a variation of 7.5 was recorded. The relatively large variation is due to the inaccuracy inherent in audiometry, which cannot be compensated by the Békésy technique. The distribution range was -4 to 24 dB. On the basis of the acquired PTS the 22 subjects were subdivided in 2 groups of identical size. Discriminant analysis using the method by Mahalanobis seperated the 2 groups at a significance level of p = 0.0074. For discriminant analysis the two most conclusive variables, i.e. reduction in writing amplitude and regression of the threshold shift, were considered.

In view of the small PTS, the inaccuracy inherent in audiometry plays a relatively important role. Therefore a relativ great part of the variance is not evaluable by discriminant analysis.

Inspite of the small number of cases studied, the author maintains that these findings constitute first evidence of the suitability of this dip in the high-tone range for predicting PTS. It goes without saying that further extensive studies are indispensable. In Austria such a study is currently under way at the VOEST steel mill in Linz, where apprentices are examined. I trust that I will be able to report on the first results obtained in this study at the next meeting.

3. COCHLEAR EMISSIONS

I was asked by the organizers to discuss the suitability of cochlear emissions for predicting chronic noise-induced hearing loss. Cochlear emissions were first described by Kemp (1978,1979), who looked for an echo from the cochlea.

Ever since, 2 types of acoustic output (often enough referred to as echoes) have been known: evoked emissions mentioned above and spontaneous emissions.
To begin with, it would seem important to know whether these emissions are normal or abnormal events. There is presumably a normal emission (Gold, 1948), which occurs in the course of normal hearing. However, our current microphones are not sensitive enough for detecting it. It is well known, that in the presence of a pathology the nervous system continues to exercise its physiologic functions spontaneously, i.e. in the absence of the requisite trigger stimulus. Both spontaneous cochlear emissions and evoked acoustic outputs appear to be tantamount to such abnormal functions (Davis 1983). That we are dealing with abnormal events originating at sites of minor cochlear lesions is supported by the following observations: several authors (Rutten 1980, Johnsen and Elberling 1982, Schloth 1982, Grandori 1983) reported that spontaneous and evoked outputs are not consistently recordable in all normal subjects. There is evidence that these events most commonly occur in patients with minor sensorineural deafness (Fritze 1983). They are, however, not seen in subjects with a hearing handicap of more than about 25 dB. That they are seen in some patients with normal audiograms may have a simple explanation: audiometry is not accurate enough for consistently detecting these injuries. It is known from histological studies that, inspite of the loss or damage of some hair cells, the audiogram may be normal or at least near-normal (Ward and Duvall 1971, Schuknecht 1974).

To illustrate spontaneous emissions I should like to present the case of a 48-year-old female with a ventricular septal defect and repeated episodes of hypotension. Audiometry revealed minor hearing loss. From this ear 2 cochlear emissions were recorded (using Fourier transformation. Zurek 1981, Wit et al.1981). That emission at about 1780 Hz was found to be present in 12 different examinations. As the frequency of these outputs varied from examination to examination, they were centered and averaged. The resultant trace is shown in Fig. 6. It consists of an extremely narrow frequency range with a somewhat wider base. This may reflect an inadequate synchronization at the margins of the cochlear site from which the outputs originate with resultant slightly higher or lower oscillation frequencies. Another conspicuous feature is that the base becomes continuous with the baseline of the curve. This base-line can easily be shown to be produced by the noise generated by the microphone. The use of a more sensitive microphone may, therefore, be expected to shed some light on the frequency characteristics of this emission.

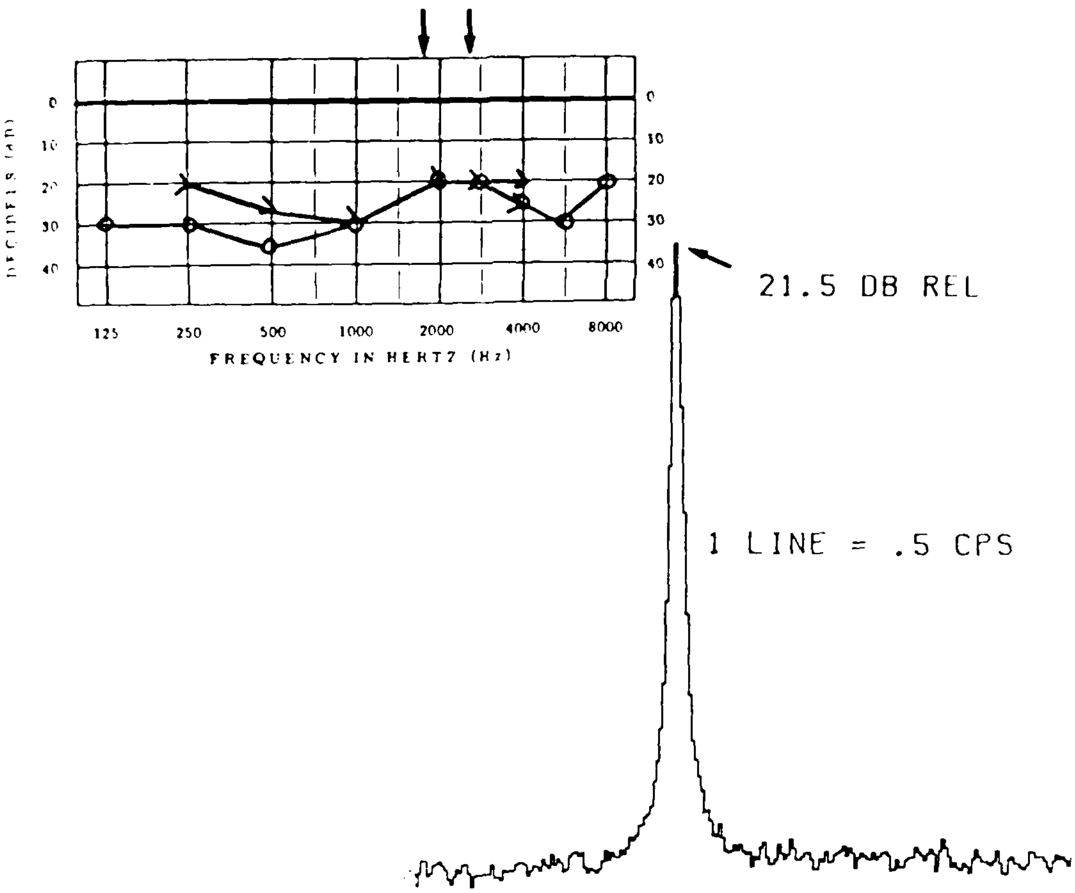


Fig. 6: A 48 years old female subject. Sites of spontaneous emissions are marked by arrows in the audiogram. The emission at about 1780 Hz was investigated 12 times; the average is given. In this case the microphone (B.A.K.4145) simply lied at the entrance of the outer ear canal. The signal was than A-weighted and outside the camera silens a Fourier transformation was calculated (B.a.K.2033, 4000 lines).

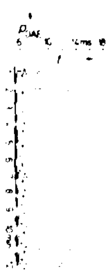


Fig. 7: The reduction of amplitude of a cochlear emission after offset of a masker of 40 Hz (112 dB SPL); also the recovery is shown. (from Zwicker 1983).

Cochlear emissions occurring after TTS experiments are equally of interest (Kemp 1982, Zwicker 1983, Fig. 7). Exposing subjects with spontaneous cochlear outputs, the author found the emission to disappear when administering interindividually veriable, adequate sound energies. However, the output recurred after about 15 minutes, initially showing some deformation and a lower frequency. In the interval uhat may be described as secondary emissions appeared in the periphery. These may be explained by an exposure-related interference with the synchronizing potential responsible for the primary emission, with other potentially emitting sites becoming active (Fritze 1983).
These TTS experiments are, no doubt, quite productive for inner ear research. But as the events described are not recorded from normal cochleas, I do not think they can be used routinely for predicting a permanent threshold shift. Further studies, particularly when using more sensitive microphones, may well furnish new insights into this problem. At any rate, the auther intends to follow-up the matter.

ACKNOWLEDGEMENT

The author gratefully acknowledges the assistance granted by VIENNATONE COMP.

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BIOCHEMICAL MECHANISMS AFFECTING SUSCEPTIBILITY TO NOISE-INDUCED HEARING LOSS

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INTRODUCTION

Noise-induced hearing loss (NIHL) caused by chronic exposure to sound pressure levels above 85 dB(A), i.e. in the upper part of the physiological region of hearing, seems to be mainly a problem of energy deficit of the hair cells. The big differences in individual susceptibility to NIHL indicate that some yet unknown factors might be involved in the respective pathological processes. In order to determine such possible factors, the basic biochemical processes are discussed and some experimental evidence of special biochemical influences on susceptibility to NIHL is described.

1. Basic biochemical mechanisms of potential production

The primary auditory receptors are the hair cells, situated in epithelia which separate fluids of different ionic composition. The apical surfaces of the hair cells carrying the mechanosensitive hair bundles face the endolymph, a fluid of high K^+ concentration. The basolateral surfaces contact a fluid rich in Na^+ and similar to the extracellular fluid (cortilymph, perilymph).

The receptor potentials are produced by a change of the conductance of the hair cell membrane. In vivo, the permeating ion carrying most of the current is K^+. However, the transduction channel in hair cells is non-specific. From in vitro experiments, the relative signal amplitude values for different ions were found to be

K^+: 1.0, Li^+: 0.9, Na^+ : 0.9, Rb^+: 1.0, Cs^+: 1.0, NH_4^+ :1.3, Ca^{2+}: 0.3, $(CH_3)_4N^+$:0.2, Mg^{2+}:0.0 (Corey and Hudspeth, 1979)

As in other membranes, there are also interactions of different ions at the hair cell membrane, e.g. Ca^{2+} ions in the endolymph are necessary for the response. With a K^+ solution at the apical surface of the hair cell, the microphonic current was abolished if the Ca^{2+} concentration was reduced to below 10 µmol/l.

Under physiological conditions, K^+ is the operating ion. When, for example, Na^+ was substituted for K^+ in the cochlear endolymph, the response was irreversibly blocked (Konishi et al., 1966). From the above-mentioned results it may be concluded that the intracellular accumulation of Na^+ must have caused this inhibition, by the following mechanisms:

a) Na^+ must be pumped out of the cell by means of an energy-consuming process.

b) An increase of intracellular Na^+ induces a loss of stored Ca^{2+} from the mitochondria and an increase of cytosolic free Ca^{2+} concentration. At an increased cytosolic Ca^{2+} concentration, membrane permeability for Na^+ and K^+ may be increased. Additionally, at increased cytosolic Ca^{2+} concentrations, energy metabolism of the cell is stimulated in order to restore the original state of the cell (for a review see Günther, 1981).

These mechanisms therefore lead to an increased energy consumption and in the case of energy exhaustion, to irreversible damage of the hair cells.

2. Energy requirement of the inner ear

In contrast to the passive process of sound transmission and impedance matching in the middle ear the mechano-electrical transduction within the inner ear is an active, energy-consuming process. Von Békésy (1951) has shown that the electrical energy contained in the cochlear microphonics, as well as in the steady displacement response of the cochlear is larger than the energy of the input stimulus. The hair cells function as energy amplifiers, their energy consumption increases with increasing acoustic stimulation.

The energy supply from blood vessels to the hair cells takes place via the perilymph - specially the cortilymph - for the organ of Corti itself does not contain blood vessels.

Biochemical analyses of substances in the perilymph which are essential in the energy metabolism, gave controversial results. Scheibe et al. (1981) reported no major change in glucose, pyruvate and lactate concentration of the perilymph after 1 h of exposure to intensive noise. In contrast to that, Schnieder (1974) reported an increase of the lactate concentration of the perilymph after noise exposure.

However, these experiments do not describe an exact energy balance, because endogenous energy reservoirs may be involved such as glycogen and lipids being present in the hair cells in relatively high concentrations and the glycogen content of hair cells decreased after noise exposure. (For review see Schätzle and Schnieder, 1979).

Other metabolic alterations, e.g. changes in nucleic acid and protein metabolism or lysosomal enzyme activity depend on the duration and intensity of noise exposure.

All these different alterations in the cell metabolism are influenced by the intracellular Ca^{2+} concentration.

3. Factors influencing hearing loss

Thus, all conditions that increase energy consumption and decrease energy supply of the hair cells can produce hearing loss when there is no compensation for the energy deficit. Beside chronic exposure to intensive noise, an additional increase of the permeability may additionally enhance the energy metabolism of the hair cells.

These effects can be reversible when permeability and energy metabolism are normalized before cell death occurs. According to the time course of the pathobiochemical mechanisms, the process can be acute or chronic.

The general pathobiochemical mechanism for each cell death is the increase of the cytosolic Ca^{2+} concentration (Farber, 1981), leading to energetic exhaustion of the cell.

Effects that influence the cell permeability and the energetic state of the hair cells, may be a reduced Mg concentration or an increased catecholamine concentration.

a) Effect of Mg deficiency

Normal cell membrane permeability depends on the extracellular concentrations of the divalent cations, Ca^{2+} and Mg^{2+}. In experiments with rats fed an Mg-deficient diet leading to a severe reduction of serum Mg concentration and in experiments with cultured cells grown in a medium with low extracellular Mg concentration, cell membrane permeability was enhanced, followed by an increased passive ion flux and increased energy-dependent ion pumping (Günther, 1981; Ising et al., 1981) and thus an increase in the energy requirement of the cell.

b) Effect of increased catecholamine levels

Catecholamines act as α - and ß- agonists according to the numbers of the α - and ß-adrenergic receptors of the target cells. α - agonists can increase cell membrane permeability, cellular Ca^{2+} metabolism and energy metabolism (Exton, 1981; Hadden et al., 1979; Tsien et al., 1982; Reinhardt et al.,1982; Rasmussen and Goodman, 1977).

ß - agonists induce an increased uptake of extracellular Ca^{2+} e.g. in heart muscle cells via adenylate cyclase, cAMP, activation of a cAMP-dependent protein kinase, phosphorylation of calciductin, a membrane-bound protein, mediating the Ca^{2+} influx (Rinalds et al., 1981).

To our knowledge, there have been no reports on α or β - receptors of hair cells. Therefore, the quantitative role of these general mechanisms cannot be defined for the hair cells.

Beside a possible direct effect on the hair cells, catecholamines can act on the smooth muscle cells of the cochlear arteries, leading to an altered contraction of these cells.

Again, this effect depends on the numbers of α- and β- adrenergic receptors of these vessels.

As these numbers may vary in various parts of the vascular system and no reports on α - and β -receptors of the inner ear arteries are available, the effect of catecholamines on the cochlear blood flow cannot be predicted.

To demonstrate sympathicoadrenergic effects on the cochlear blood flow,Maass et al. (1977) compared the endolymphatic pO_2 of sympathectomized and normal cats (Fig. 1) as a function of the mean aortic blood pressure. The experiment shows the influence of the sympathetic on the cochlear blood flow regulation. Through sympathectomy this regulation changes from the peripheral type to the central type.

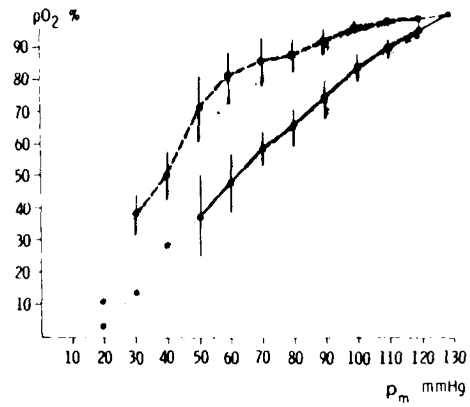

Fig. 1 Oxygen partial pressure (pO_2) as a function of the mean aortic blood pressure (p_m)

- ╋ - 5 sympathectomized cats

—╋— 5 non-sympathectomized cats (mean values (Maass et al., 1977) ± s.d.)

Since the contraction of smooth muscle cells is regulated by intracellular Ca^{2+}, it can be understood that at reduced Mg the vasoconstriction and the effect of vasoactive hormones are enhanced (Altura and Altura, 1981; Turlapaty and Altura, 1982).

In earlier experiments with rats, the authors could demonstrate that in Mg deficiency states, the release and urinary excretion of catecholamines - particularly noradrenaline - was enhanced (Günther et al., 1978). When Mg-deficient rats were additionally exposed to noise, catecholamine excretion became furthermore increased. Therefore, noise stress may act in two ways: 1) directly on the hair cells and 2) through an increased release of catecholamines.

4. Experimental proof of influences on susceptibility to NIHL

There are some experimental results available which de-

monstrate the influence of the two mechanisms described on the pathogenesis of NIHL -

a) Mg deficiency and b) increased catecholamine concentrations.

a) Mg deficiency

NIHL of guinea pigs with varying Mg intake was found to increase with decreasing Mg content of the drinking water while the Mg content of the food was low and constant (Table I) (Ising et al., 1982).

Table I

Magnesium content of drinking water and hearing threshold shift of guinea pigs after noise exposure for 4 weeks. (Mg content of food 3 m mol/kg)

Group No.	Mg content (mmol/l)	Hearing threshold shift (dB)	
1	4.5	16.8 ± 12.5 (n = 14)	
2	2.5	22.7 ± 12.8 (n = 13)	++
3	0.5	34.2 ± 11.9 (n = 14)	+

Mean values $\pm$ SD

Significance levels: $^{+}p \leq 0.05$; $^{++}p \leq 0.01$

In a group of 9 Mg-deficient guinea pigs, the hearing threshold shift after 10 days of noise exposure was negatively correlated to the Mg content of the perilymph (Fig.2).

Similar results were obtained in rats (Joachims et al., 1983). Normotensive albino rats (NR) on an Mg-rich diet exhibited a mean permanent hearing loss of 14 dB after 12 weeks of noise exposure, whereas the mean hearing loss of rats on a low-Mg diet amounted to 24 dB. In spontaneously hypertensive rats (SHR), the Mg influence on NIHL was even stronger(Table II).

The individual hearing losses were negatively correlated to the perilymph Mg (PMg) (Fig. 3). Mg deficiency alone caused no hearing loss or other pathological defects, because in this experiment the Mg deficiency was mild in comparison to an earlier experiment (Günther et al., 1978; Ising et al., 1981). Then the animals lost weight during the last 8 weeks of treatment, whereas this time there was an increase of weight even in the Mg-deficient rats till the end of the experiment.

In Table II, the Mg concentrations in serum, erythrocytes, myocardium and perilymph are given together with the systolic blood pressure because in earlier experiments we could demonstrate noise-induced stress effects on the mineral metabolism of the myocardium as well as on the blood pressure. In this experiment the only extraaural noise effect in NR was a slight decrease of E Mg. The SHR, being more sensitive to stress,exhibited noise-induced decreases of myocardial Mg(M Mg)

and a slight increase in blood pressure in the Mg-deficient group. Like in earlier experiments (Ising et al., 1981), noise in combination with mild Mg deficiency (5.8 mmol/kg diet) did not cause a decrease of M Mg, whereas under severe Mg deficiency (1.6 mmol/kg diet) noise caused an M Mg decrease from 31.2 to 26.8 mmol/kg dry tissue.

In the human population, similar differences in M Mg contents exist. Elwood et al. (1980) have given mean myocardial Mg levels in humans in dependence on age and cause of death. The greatest comparable differences were found between groups of subjects who died at an age above 65 years from ischaemic heart disease - Mg: 6.4 $\pm$ 1.1 mmol/kg wet tissue - and those who died under 45 from other causes - Mg: 7.7 $\pm$ 1.1 mmol/kg wet tissue. When comparing these figures with those from Table II by setting the highest value equal to 1, the mean myocardial Mg values differed in humans from 1 to 0.83 and in the rat experiment for NR from 1 to 0.9 and for SHR from 1 to 0.86. Can Mg therefore have a similar importance for human NIHL? Some additional information can be drawn from the analysis of E Mg concentrations. Although it is clear that there is no direct causal relationship between E Mg and NIHL, E Mg may serve as an indicator of P Mg. In Fig. 4, the PTS values have been plotted as a function of E Mg. By comparison with Fig. 3, it is evident that the correlation of PTS and P Mg has been quite similar to that between PTS and E Mg.

In our experiment, the different Mg intake resulted in E Mg values between 2.9 $\pm$ 0.32 and 4.72 $\pm$ 0.34 mmol/kg dry

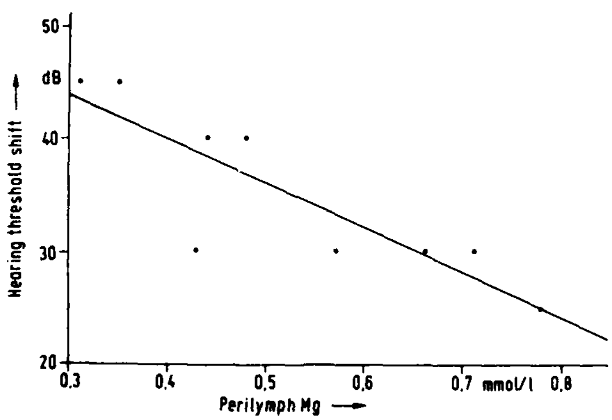

Fig. 2 Correlation between hearing threshold shift and perilymphoid Mg of 9 Mg-deficient (like group 3) guinea pigs after 10 days of noise exposure /L_{eq} = 95 dB(A), 16 h/day_7; r = - 0.86.
Perilymph samples between 5 and 10 μl were taken through the opened tympanic bulla and the round window by means of a Hamilton syringe and Mg determined by atomic absorption spectroscopy.

Table II

Effects of 10 weeks of noise exposure and different Mg content of the diet on normotensive rats (NR) and spontaneously hypertensive rats (SHR).
PTS: Hearing threshold shift 10 days after end of noise exposure;
S Mg: serum Mg; E Mg: erythrocyte Mg; M Mg: myocardial Mg; P Mg: perilymph Mg.

Group		Noise Leq (16 h) dB (lin)	Mg content mmol/kg	PTS dB	S Mg mmol/kg	E Mg mmol/kg dry tissue	M Mg mmol/kg dry tissue	P Mg	Syst.blood pressure mm Hg
NR	control	59	130	-	1.04	4.98	34.5	-	121
NR	noise	108	130	14	0.98	4.45 *	34.6	0.86	117
NR	Mg-def. control	59	4,5	-	0.25	3.21	31.5	0.67	124
NR	Mg-def. noise	108	4,5	24	0.23	3.24	31.2	0.68	123
SHR	control	59	130	-	1.15	4.72	37.0	0.87	196
SHR	noise	108	130	7	1.09	4.83	32.8 **	0.84	194
SHR	Mg-def. control	59	4,5	-	0.24	2.90	35.3	-	188
SHR	Mg-def. noise	108	4,5	23	0.23	3.12	31,9 **	0.67	196 *

Significance levels for differences between noise- and control groups
* : $p \leq 0.05$; **: $p \leq 0.01$

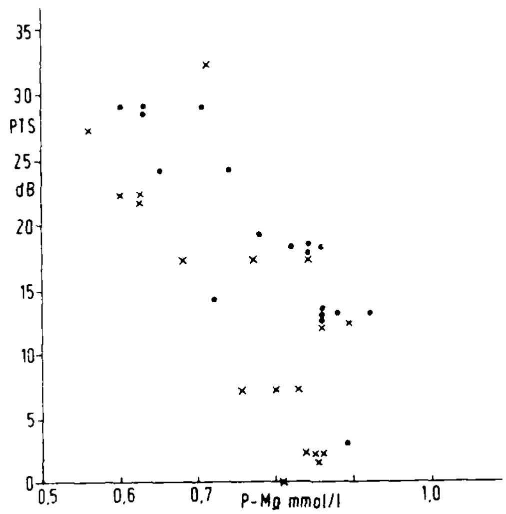

Fig. 3 Noise-induced permanent threshold shifts (PTS) in normal rats • and SHR x 10 days after the end of noise exposure (3 months, 104 dB, 16 h/day) as a function of the Mg concentration in the perilymph (PMg). Perilymph was taken from the live, anaesthetized rat.

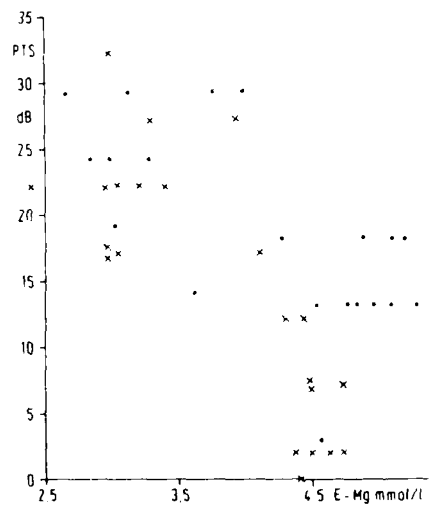

Fig. 4 Noise-induced permanent threshold shifts (PTS) in normal rats • and SHR x 10 days after the end of exposure as a function of the Mg concentration in the erythrocytes (EMg), used as an indicator for PMg.

tissue. These values permitted a comparison with human E Mg values. In a group of 30 workers, we found a mean value of

7.5 ± 0.7 mmol/kg dry cells for the five persons with the highest E Mg, the five lowest E Mg values, being 5.1 ± 0.1 (Ising et al., 1980), resulted in a variation of 1 to 0.68. The corresponding figures in the rat experiment were 1 to 0.64 for NR and 1 to 0.60 for SHR.

The Mg decrease in the perilymph (1 - 0.77 for NR and SHR) was slightly smaller than in the erythrocytes but totally incomparable to the serum Mg concentrations. E Mg seems to be a suitable model for P Mg.

These considerations suggest that in the human population the variability of P Mg may be of a comparable magnitude to the experimentally induced P Mg variations in rats. Therefore it is possible that Mg may have a comparable importance for human NIHL as in the animal experiments reported.

b) Increased catecholamine levels

In a 3-month experiment, Wistar rats were noise-exposed and injected with catecholamines 3 times per week; the controls received NaCl (Uhlig, 1983). Hearing threshold shifts 3 to 8 h after termination of the noise exposure are given in Table III.

Table III

Differences of hearing thresholds in Wistar rats as compared to controls 3 to 8 h after 10 weeks of noise exposure plus three subcutaneous injections per week,

Group 1: NaCl, Group 2: epinephrine 100 µg/kg body weight +
norepinephrine 400 µg/kg " "

Group	Hearing thresholds shifts (dB) Frequency: 5 kHz	10 kHz	20 kHz
1	30 ± 4	37 ± 3	43 ± 5
2	40 ± 8	55 ± 6	64 ± 6

The catecholamine injections without noise exposure had no effect on the hearing threshold.

Since nicotine is known to increase catecholamine release, nicotine may also increase the susceptibility to NIHL. Handrock and Matthias (1982) reported a noise exposure experiment where half of the rats received 5 mg/kg body weight and day nicotine per os.

The results are shown in Fig. 5. Three days after the treatment, the mean hearing threshold shift of the nicotine group was 26.4 dB in comparison to 17.5 dB in the controls.

Although Bobbin and Gondra (1976) did not find an influence of nicotine on human NIHL there may be some effect because of the mentioned increase of catecholamine release by nicotine.

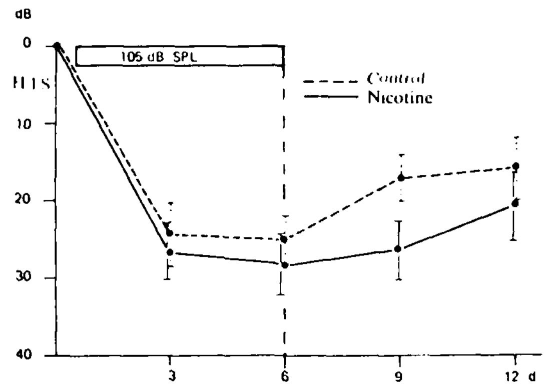

Fig. 5 Hearing threshold shift (HTS) of rats during and after noise exposure.

- ● - Control (mean values ± s.d.)

—●— Nicotine, 5 mg/kg body weight and day (Handrock and Matthias, 1982).

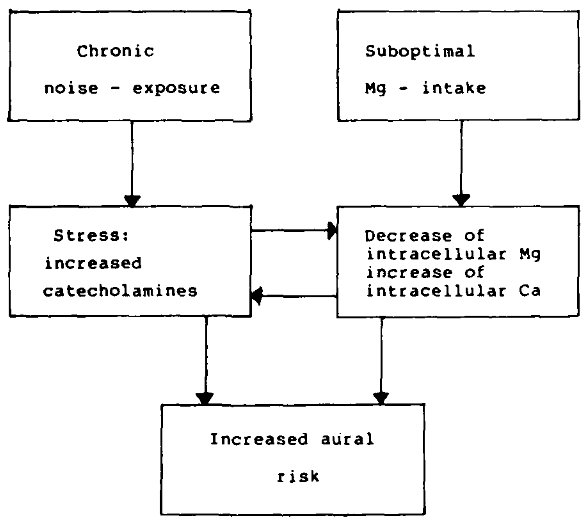

Fig. 6 Chronic noise exposure in combination with suboptimal Mg intake leads to an interaction of stress and Mg decrease resulting in increased aural risk

The reported results show that increased catecholamine concentrations increase the susceptibility for NIHL. Further research must show whether this is caused by vasoconstriction of the cochlear blood vessels or by a direct catecholamine influence on the hair cells.

CONCLUSION

Two important conditions for increased susceptibility to NIHL are

1) Mg deficiency and
2) increased catecholamine concentrations.

These two conditions may act simultaneously and thus have an additive effect on susceptibility to NIHL.
Beyond this, these two conditions were found to be interrelated (Fig. 6) and thus amplifying each other through a feedback mechanism (Ising et al., 1981).
Since the basic mechanisms of sound transduction in the inner ear are related to membrane permeability and energy-dependent transport mechanisms both of which are influenced by Mg and catecholamines, the long-term interaction of Mg decrease and increased catecholamine concentrations are likely to increase the risk for human NIHL.

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NEW PROCEDURES FOR THE EVALUATION OF HEARING PROTECTORS

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INTRODUCTION

Use of personal hearing protection devices represents the most common means of reducing the level of hazardous noise reaching the ears of the individual subjected to such noise. Perhaps the most common and universally accepted means of determining the amount of noise attenuation provided by the hearing protector is known as the real-ear attenuation-at-threshold (REAT) procedure. The REAT procedure forms the basis of several national standards for the assessment of hearing protector attenuation, including those of the United States (ASA Z24.22-1957 and ANSI S3.19-1975), Great Britain (BS 5108:1974) and Canada (CSA Z94.2-1974). The REAT technique simply involves the measurement of hearing threshold for narrow-band or sinusoidal acoustic signals both with and without the hearing protector placed on the listener. The difference in the two hearing thresholds,

protected and unprotected, represents the amount of attenuation provided by the hearing protector.

When the attenuation estimates derived in this manner are applied to typical hazardous noise environments, however, an assumption of attenuation linearity is invoked. That is, low threshold-level acoustic signals are used in the REAT procedure to determine the amount of protection to be provided by the hearing protector in the high levels of noise in which it is to be worn. Hence, an assumption made is that the attenuation measured at low sound levels is the same provided by the protector at high sound levels.

Several previous investigators have examined the critical assumption of attenuation linearity. A variety of methods have been employed with wide disparity in outcome; some supporting linearity, others suggesting reduced attenuation at high sound levels. Three basic approaches have been used by previous investigators to assess the linearity of hearing protector attenuation. These are: (1) comparison between loudness judgments of high-level sound made in the protected and unprotected conditions (Webster, 1955; Hershkowitz and Levine, 1975; Weinreb and Tougher, 1960; Jay, 1977); (2) differences between physical measurements made with microphones on cadavers, artificial heads, or real ears in the protected and unprotected conditions (Martin, 1979; Osmundsen and Gjaevenes, 1981; Rood, 1982; Humes, Konkle and Sanders, 1982; Berger and Kerivan, 1982; Preves and Pehringer, 1983); and

(3) differences between the ability of an air-conducted noise to mask a bone-conducted pure tone in the protected and unprotected conditions (Damongeot and Lataye, 1982; Brinkmann and Brocksch, 1976; Humes, Konkle and Sanders, 1982).

For the majority of these studies measurements were made with the proposed experimental procedure and compared to the attenuation estimates obtained with the REAT technique. Seldom was more than one experimental technique explored. Moreover, the experimental technique was typically applied at just one high noise level. In an effort to better understand the wide disparity in outcome of these studies, several of these same procedures were evaluated in this study on the same group of subjects employing the same acoustic signals and the identical acoustic test space for all procedures and listeners. In particular, attenuation estimates were obtained with two loudness-related procedures (magnitude estimation and reaction time), a masked bone-conduction procedure and a physical measurement (miniature microphone applied to real ears). Results from 10 hearing protectors (5 muffs and 5 plugs) are compared to attenuation estimates derived with the REAT technique.

MATERIAL AND METHODS

The methods employed in this investigation have been described previously in Humes, Konkle and Sanders (1982) and Humes (1983). Briefly, ten normal-hearing young adults served as subjects. The acoustic signals and test space were as required by the American Standard (ANSI S3.19-1975) which makes use of 1/3-octave-bands of noise presented to the listener seated in a diffuse sound field. An exception to this generalization involves the masked bone-conduction

procedure in which different stimuli were employed (octave-band masker and sinusoidal bone-conducted signal).

The experimental procedures employed in this study require brief review. For the two loudness-related tasks, the basic approach was the same, although the means of estimating loudness differed considerably. In one method, a magnitude-estimation procedure (Stevens, 1975) was used to measure the growth of loudness with increase in stimulus intensity in both the protected and unprotected conditions. Two such functions are illustrated in Figure 1. The open circles represent the group data for the unprotected condition while the solid circles show the data for the protected condition. These data were obtained for protector No. 8 (an earplug) for a 1/3-octave-band of noise centered at 4000 Hz. The horizontal shift of the solid circles reflects the amount of attenuation provided by the protector at low (48 dB SPL) and high (88 dB SPL) noise levels.

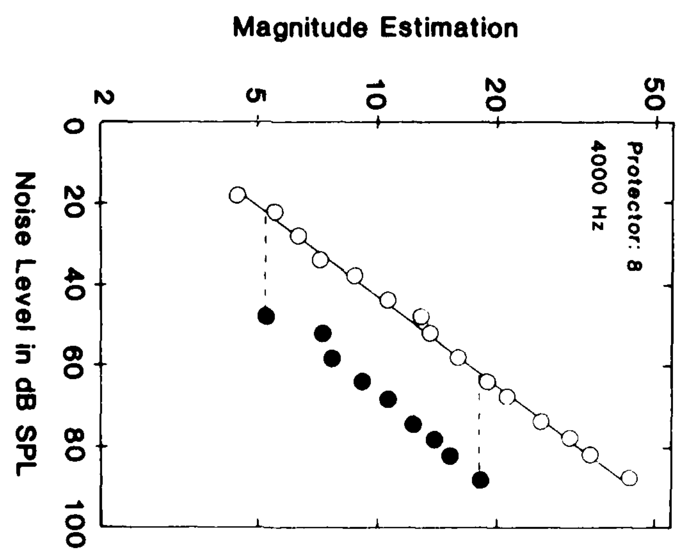

Fig. 1. Data obtained with magnitude-estimation procedure.

In the magnitude-estimation procedure, subjects simply judge the loudness of the noise presented at a randomly

selected intensity and assign a number to the stimulus on the basis of the perceived loudness. The other loudness-related procedure provides a less direct estimate of loudness and is based on the relationship between a sound's loudness and the time required by the subject to react to its presentation [See Scharf (1980) for review]. This procedure is referred to as the reaction-time paradigm. Basically, the louder a sound, the shorter the reaction time. This is evident in Figure 2 which displays two reaction-time/intensity functions, one for the unprotected condition (open circles) and one for the protected condition (solid circles). Again, the horizontal displacement of the protected function reflects the amount of attenuation over a range of noise levels (approximately 50-90 dB SPL). The data shown are group data (N = 10) for protector No. 1 and a 1/3-octave-band of noise centered at 4000 Hz.

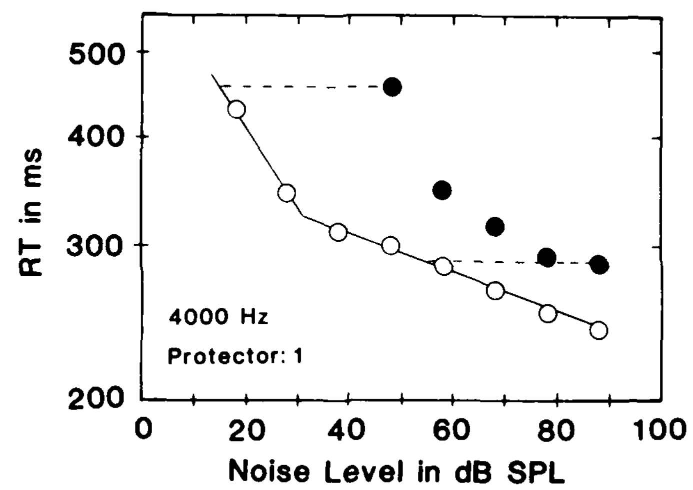

Fig. 2. Typical results from reaction-time paradigm.

The physical measurement technique made use of a miniature microphone and accompanying interface (Starkey Laboratories) which was carefully placed in the subject's ear canal. Sound pressure levels measured by the microphone in the subject's ear canal for an 85-dB-SPL sound-field noise level were recorded for both the protected and unprotected conditions. The difference in these two values furnishes an estimate of attenuation at high noise levels. Only 1/3-octave-bands of noise centered at 1000 and 4000 Hz were examined with this procedure. Due to difficulty inserting the plug-type protectors to the recommended depth with the

microphone remaining in the ear canal, moreover, this technique was only applied to muff-type protectors.

Finally, the masked bone-conduction procedure measured the ability of an octave-band of air-conducted noise to mask a bone-conducted pure-tone signal centered in the noise. The bone-conducted signal was applied to the forehead with a Radioear B-70A bone oscillator. The average octave-band level of the noise was 83 dB SPL. Threshold for a 500-ms signal was measured with and without the hearing protector in place. The difference in these two masked thresholds provides an estimate of the attenuation provided by the protector. For the unprotected condition, at least 45 dB of masking was produced for all subjects. This assured that when the protectors were in place and reduced the masking of the bone-conducted signal by attenuating the air-conducted sound-field noise, attenuation values of 45-50 dB could be measured validly.

Each of the ten subjects had their own set of earplugs. For muff-type protectors, three separate hearing protectors were rotated in use. Table 2 in Humes (1983) provides a list of the hearing protectors used in this study.

RESULTS

Results obtained with the various procedures are shown in Figures 3 and 4 for the muff-type and plug-type protectors, respectively. Average data are shown for noise bands centered at 1000 and 4000 Hz. Several observations can be made from the data displayed in these figures. First, the two loudness-related procedures, magnitude estimation (solid circles) and reaction time (open circles), suggest that attenuation is linear over the range from 50 to 90 dB SPL. Second, although these two procedures suggest linearity of attenuation, they both estimate attenuation to be from 3 to 15 dB less than that measured with the standard REAT procedure. Third, the miniature microphone measurements (Figure 3, open triangle) and the masked bone-conduction procedure (solid triangle, 4000 Hz only) yield estimates of

attenuation at high noise levels that are in much better agreement with the results of the REAT technique. No data were obtained with the masked bone-conduction technique at 1000 Hz in an effort to avoid the potentially confounding influence of the occlusion effect.

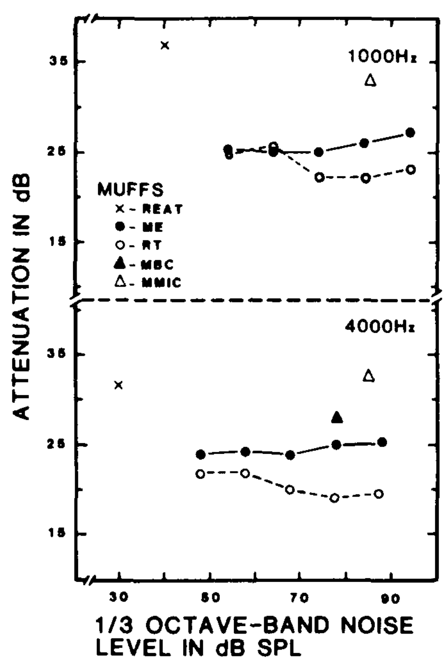

Fig. 3. Mean attenuation for five earmuffs at 1000 and 4000 Hz.

The general observations drawn from the data pooled from all five muffs or all five plugs shown in Figures 3 and 4 apply as well to the data obtained from individual protectors. Moreover, additional data obtained at 2000, 3150 and 6300 Hz for all procedures except the miniature-

microphone technique are also supportive of these general findings (Humes, 1983).

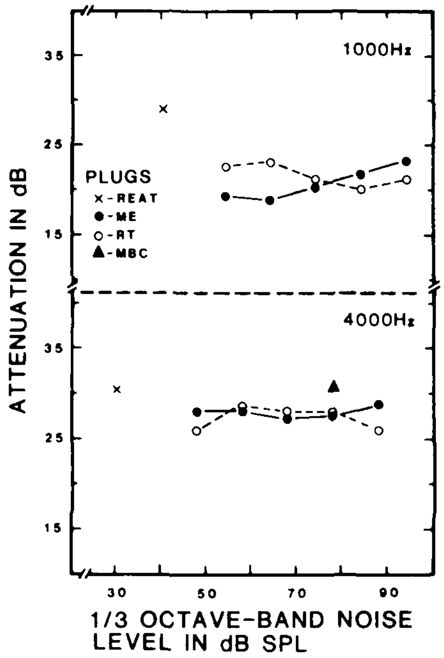

Fig. 4. Mean attenuation for five earplugs at 1000 and 4000 Hz.

CONCLUSIONS

Several conclusions can be drawn from the results of the present study. First, the assumption of attenuation linearity appears to be a valid one for the ten protectors evaluated in this experiment. Linearity was observed in this study for 1/3-octave-band noise levels up to approximately 90

dB SPL. A broad-band industrial noise having 1/3-octave-band levels of this intensity would approach an overall level of 95-105 dB SPL depending upon the spectral shape of the noise.

Second, although the two loudness-based procedures evaluated in this study indicated that attenuation was linear from 50-90 dB SPL, they consistently yielded lower estimates of hearing-protector attenuation. The reason for this underestimation is not clear. This finding, however, indicates that comparison of attenuation estimates derived with the REAT procedure to those derived with either method at only a single high noise level would lead one to conclude erroneously that attenuation decreased at high noise levels. The present data suggest that attenuation derived with these two loudness-based procedures is less than that derived with the REAT technique not only at high noise levels but at noise levels only 10-15 dB greater than those employed with the REAT procedure. Attenuation in linear but reduced, relative to that derived with the REAT method.

Third, both the masked bone-conduction procedure and the real-ear miniature-microphone technique yielded attenuation estimates within 3-4 dB of those derived with the REAT technique. Each procedure has associated advantages and disadvantages. Regarding the miniature-microphone measurements, advantages include the objective nature of the data and the ability to derive personal noise attenuation values for individual wearers as opposed to applying group data to individuals (e.g., Berger and Kerivan, 198[illegible]; Preves

and Pehringer, 1983). The primary disadvantage with this method at present concerns the inability to use the technique with plug-type protectors due to the physical size of the microphone. The increased emphasis on the miniaturization of microphones, however, may soon alleviate this problem.

The particular masked bone-conduction procedures employed in this study also had some inherent difficulties. The frequency of the bone-conducted signal was restricted to frequencies $\geq$ 2000 Hz, for instance, to avoid the potentially confounding influence of the occlusion effect when comparing unprotected to protected hearing thresholds. In addition, the range of noise levels available is restricted due to limitations in output of the bone-conduction transducer. Finally, averaged data from groups of subjects would appear to be necessary. An advantage, however, is that the same basic threshold-measurement procedures used with the REAT method can be used with the masked bone-conduction procedure. Moreover, the problems mentioned previously regarding the occlusion effect and the output limitations of the bone oscillator have been avoided in the masked bone-conduction procedure developed by Brinkmann and Brocksch (1976).

The masked bone-conduction and miniature-microphone methods should both continue to be explored as supplements to the REAT procedure. A procedure enabling the assessment of attenuation at high noise levels is needed in national standards to ensure linearity of attenuation in the protector being evaluated.

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ACKNOWLEDGEMENTS

This work was supported by a grant (R01-OH00895) from the National Institute of Occupational Safety and Health. The authors express their gratitude to Kathy Lambert for typing the manuscript and Don Riggs for assistance with the illustrations.

HEARING PROTECTORS - SELECTION AND EFFICIENCY

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INTRODUCTION

Nine years after the introduction of the West German hearing conservation programme noise induced hearing loss is still the occupational disease No.1 with 2007 first compensated cases in 1982. So we must state that hearing protectors and monitoring audiometry are not as effective as we expected them to be. This paper shall contribute to increase the efficiency of hearing protective devices (HPDs) by proper selection.

TOTAL ENERGY PRINCIPLE AND HEARING PROTECTORS

One of the most important contributions on the employment of HPDs in hearing conservation programmes was the publication of Else (1973) on the reduction of the exposition level (individual rating level) by hearing protectors as a function of the wearing time; the effective sound attenuation Z_{eff} of a HPD, see figure 1, (that means the reduction of the noise dose) depends on the wearing time T after

$$(1) \quad Z_{eff} = Z_o - 10 \lg\left\{\frac{1}{8h}(T + (8h-T)\cdot 10^{Z_o/(10\ dB)})\right\} \ dB$$

wherein Z_o is the sound attenuation for a given noise.

On the basis of the total energy principle the results of Ivarsson et al. (1980) could be understood, who found out, that workers wearing high attenuating muffs showed worse hearing loss then "plug men" waering Bilsom wool after an equal exposition. Lower wearing comfort of the muffs an the worsening of the acoustical communication by the low pass filtering cause a shorter daily wearing time and in consequence a lower effective attenuation.

From this the following consequences have to be drawn:

- The HPD wearing comfort must be increased
- Overprotection and acoustic isolation especially in cases of hearing loss must be avoided
- Proper selection of HPDs for a given noise situation is necessary.

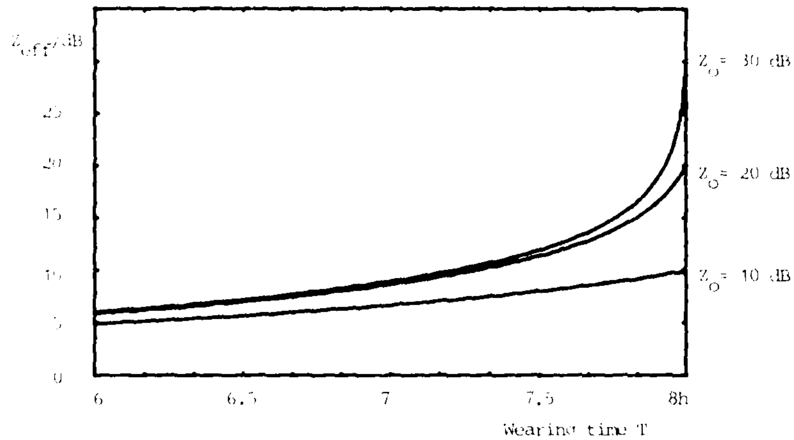

Fig. 1 - Effective sound attenuation of HPDs with Z_o = 30 dB, 20 dB and 10 dB as a function of the wearing time (after Ivarsson et al.)

WEARING COMFORT

To minimize the detraction from well-being caused by HPDs it is necessary to increase the wearing comfort. Wearing comfort is almost a subjective criteria. Therefore the user should always have the choice between different HPDs. But there are objective criteria too, which give access to testing, correlating well with the average subjective assessment.

TESTING OF HEARING PROTECTORS

Brinkmann et al. (1982) recently reported on the test methods of the German Standard DIN 32 760: Hearing protectors - concepts, safety requirements, testing. As an authorized testing institute in accordance with the West German Equipment Safety Act our institute has tested 80 types of hearing protectors not only on their sound attenuation - which is certainly an important but commonly overvalued parameter (see above) - but on a multitude of different mechanical, thermal and software properties (see figure 2). Wearing comfort correlates with all those detail tests marked with an asterisk. The testing results demonstrate, that the non-acoustical requirements on HPDs are as important as the acoustical criteria at least. About 50% of the hearing protectors do not meet the requirements.

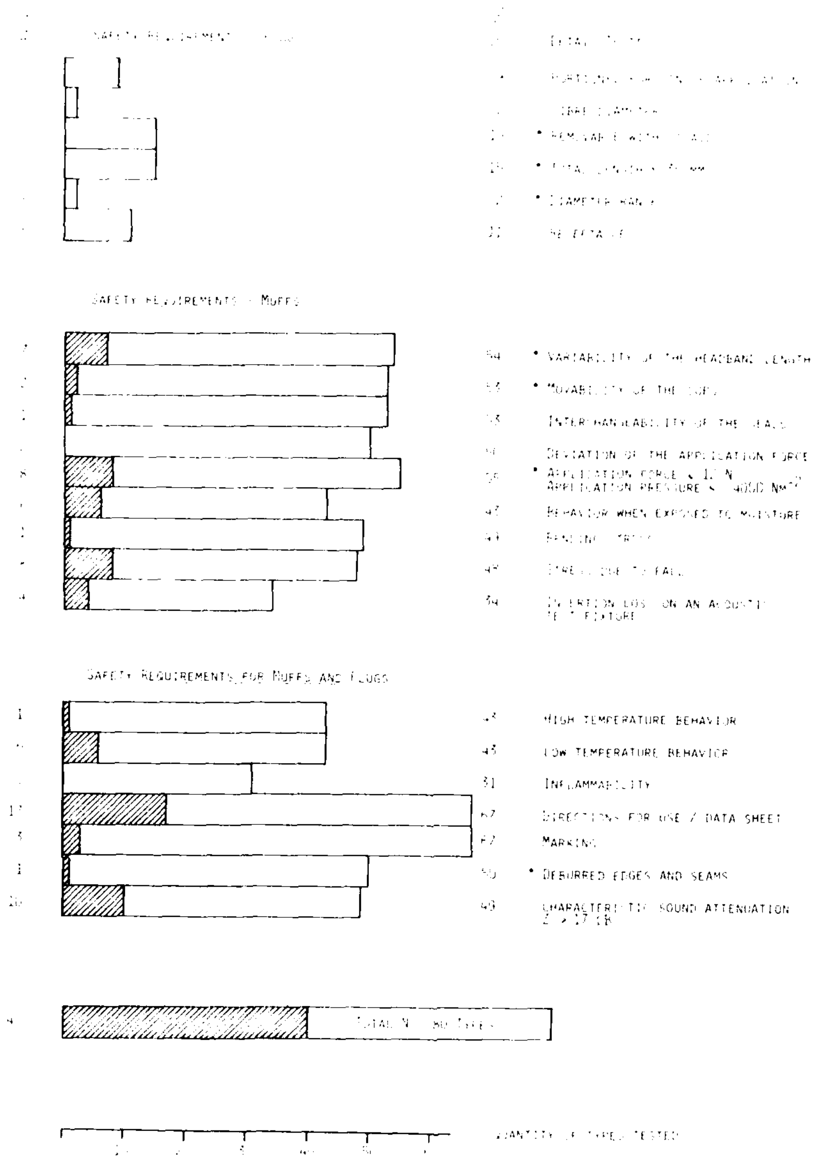

Fig. 2 - Hearing protector testing according to DIN 32 760: Numbers of detail tests carried out and cases with negative test results 1978-1983.

NIPTS-RISK REDUCTION BY HEARING PROTECTORS

Misinterpretation of the total energy principle consequences (see figure 1) might lead to the conclusion that HPDs are not effective at all at most working places. Using the ISO/DIS 1999 - Hearing loss model to calculate the damage risk results in convincing arguments for hearing protectors. After Röser (1973) the percentage of hearing loss for speech HL_S can be derived approximately from the pure tone audiogram according to

$$(2) \quad HL_S = HL_{1kHz} + \{HL_{3kHz}/2\} - 15 \quad \text{in \%.}$$

In our compensation system (based on speech audiometry!) a hearing loss $HL_S \geqslant 30\%$ can be compensated. Using $HL_S \geqslant 30\%$ as a damage risk criteria and the ISO/DIS 1999 pure tone audiogram hearing loss distribution, we can calculate the percentage of critical exposed as a function of the exposition level with sex, age and exposition time as parameters. Figure 3 shows the results for 45 years old male subjects with different exposure times t. The protective function of HPDs - e.g. a muff type hearing protector worn only 6h out of the daily 8h exposure time, with Z_O = 30 dB, Z_{eff} = 6 dB, $L_{EX,8h}$= 100 dB(A) and t = 25 years - is evident: The damage risk is reduced by this HPD from 29% below 5%. Even a not always worn hearing protector reduces the risk for NIPTS (noise induced permanent threshold shift). To increase the efficiency of HPDs suitable devices must be offered.

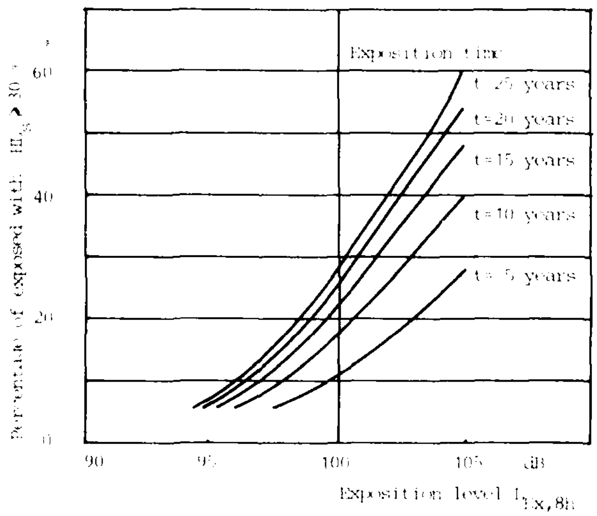

Fig 3 - Damage risk calculated for 45 years old male populations ($HL_S \geqslant 30\%$, after (2)) with exposition times 5-25 years as a function of the exposition level on the basis of ISO/DIS 1999.

HEARING PROTECTOR SELECTION STRATEGY

Hearing protectors should be carefully selected from the market with respect to the working environment. For this purpose we elaborated a selection strategy, which was successfully tested in several industries and which now is recommended by the Verein Deutscher Ingenieure (VDI recommendation 2560, 1983).

1. Type approved hearing protectors!
Hearing protectors must meet the safety requirements of DIN 32 760 (see above) after the Equipment Safety Act. Type approved hearing protectors ensure:

- a defined sound attenuation and a minimum characteristic sound attenuation $Z \geqslant 17$ dB,
- good lifetime of the HPD,
- acceptable wearing comfort.

2. Muffs or plugs?
Plugs are recommended

- at working places with permanent noise immission,
- if sweating under muffs is complained,
- if spectacles or safety glasses and hearing protectors must be worn simultaneously
- if muffs are not worn,
- if audibility and recognition of signals is of importance.

Muffs should be chosen

- if the hearing protector must often be put on/taken off, e.g. short stays in noisy areas or at intermittent noise,
- if plugs are not tolerated by reason of too narrow ear canals,
- if the user shows liability to inflammation of the ear canal, if plugs are incompatible.

3. Selection for the sound attenuation and acoustical properties of the HPD

Hearing protectors are commonly not selected from the market by acoustically trained persons. The information on the noise at the working place available is rather poor - mostly the A-weighted equivalent continuous sound pressure level and the sound impression are available. With these premises we introduced the recommended level ranges for tested HPDs (Pfeiffer, 1979). This method results in two level ranges in which the HPD under consideration should be worn. The two ranges correspond to the noise class I, middle- to high-frequency noise, or to the noise class II, low frequency noise. The noise classes are differentiated by: noise class I: $L_C-L_A < 6$ dB/ noise class II: $L_C-L_A \geqslant 6$ dB. Measurements of L_C-L_A or lists of comparable, typical noise sources (see tables 1 and 2) will help to distinguish on the basis of the sound impression.
The two recommended level ranges will be derived from the sound attenuation data d_i ($i = 1...8$, mean values for the 8 octave centrefrequencies 63 Hz-8 kHz) and s_i (standard deviations of d_i) with the following algorithm. For each of the 19 spectra in table 3 L_j must be calculated from (3).

$$(3) \quad L_j = L_G + 100 - 10 \log\left[\sum_{i=1}^{8} 10^{0.1L'_{ij}}\right] \text{dB}$$

wherein

$$(4) \quad L'_{ij} = L_{ij} - d_i + s_i; \; i = 1\ldots8; \; j = 1\ldots19; \; d_i - s_i \geqslant 0$$

L_{ij}: A-weighted test spectra (see table 3)

L_G : Lower limit rating level for the development of NIPTS L_G = 85 dB(A) after DIN 45 645, part 2.

The minimum of L_j (j = 1...8) is defined as the upper limit of the recommended level range of noise class I. The minimum of L_j (j = 9...19) is defined as the upper limit of the recommended level range of noise class II. The lower limits of the recommended level ranges are chosen 15 dB below the upper limits, if not < 85 dB(A). If the upper limits minus 15 dB are smaller than 85 dB(A) L_G = 85 dB(A) is defined as the lower limit of the recommended level range. The calculation of the recommended level ranges is carried out by the testing institute.

air-nozzles	jolt squeeze machines
band saw (wood)	knitting machines
circular saw (wood)	looms
cleaning of castings	metal forming press
concrete vibrating equipment	paper making machines
Diesel engine	pounding-up machines
electrical welding	puncher
filler	relief rotary press
flame-cutting	rock drilling machines
folding machines	spinning mill
forging hammer	straightening
grinding machines	sugar centrifugal machines
gun-nailers	wood planer
injection machines	

Table 1 - Examples of noise sources of noise class I

annealing furnace	die casting machines
blast furnace	dredger excavator
boiler blower	edge mill
bulldozers	electric melting furnace
compressors	motor generator
converter	transformers
cupola furnace	trucks

Table 2 - Examples of noise sources of noise class II

After decision for noise class I or II the A-weighted rating level at the working place shall be within the recommended level range; if so the HPD has a suitable sound attenuation.

Spectrum No. j	L_{ij} in dB; i = 1...8 Octavebands in Hz								$L_C - L_A$ in dB
	63	125	250	500	1000	2000	4000	8000	
1	51	62	71	80	88	95	96	93	-1.4
2	57	68	78	86	93	95	94	91	-0.5
3	59	71	81	89	96	95	93	87	0.5
4	63	75	84	92	96	94	92	87	1.5
5	65	77	87	93	95	94	90	85	2.5
6	67	79	89	94	95	93	89	83	3.4
7	70	81	90	94	94	93	90	86	4.4
8	73	84	91	95	95	92	89	83	5.5
9	74	85	92	94	95	92	90	82	6.4
10	77	86	93	94	94	93	87	82	7.6
11	78	88	94	94	94	91	87	83	8.5
12	78	90	92	94	94	92	88	80	9.5
13	81	91	95	94	92	89	85	79	10.6
14	83	92	94	94	93	90	86	81	11.5
15	84	92	93	95	92	89	86	77	12.4
16	85	94	93	95	91	88	82	74	13.4
17	86	95	94	93	92	87	85	79	14.5
18	88	96	91	91	91	90	84	79	15.8
19	90	93	94	93	88	86	88	89	16.7

Table 3 - A-weighted octaveband test spectra averaged from 700 industrial noise spectra (Pfeiffer, 1979).

This method has the advantage of easy selection without calculation, it avoids over- and under-protection. There are many other selection methods - some more precise included - which can certainly be used too.

If the recognition of speech and/or noise with information content - e.g. the sound of drop forging changing with the die's position - is necessary, hearing protectors with a flat attenuation curve (as with most plugs) should be preferred.

According to ISO/DIS 7731 subjective tests on the discriminibility of auditory danger signals shall be performed with at least 10 subjects (including elder and/or persons with hearing handicap) using their HPD.

Directional hearing is impaired by hearing protectors. The up/down- and the front/back-position finding with plugs seems to be better compared to muffs.

4. Subjective tests on wearing comfort

After the first three steps divers types of hearing protectors should be offered to the user's choice to exclude individual trouble wit the HPD.

CONCLUSIONS

At noisy working places, where the described selection strategy and continued motivation for personal hearing protection are applied, up to more than 80 percent of the employees wear their HPD. High sound attenuation should not longer be the most important sales promoting argument for the hearing protector, since high- and low-attenuating HPDs are needed as well. W aring comfort still must be improved; to be able to test this property objectively, we need more sophisticated test methods.

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APPLICATION OF TTS MEASUREMENTS FOR THE EVALUATION OF NOISE HAZARD A FIELD STUDY.

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INTRODUCTION

Long-term investigations of noise in coal mines reveald the problem of taking measurements at test stands with a great hazard of methane explosion. The application of conventional sound-level meters and noise dose meters is prohibited, and even special apparatus, scarcely available in most countries, cannot be applied if the concentration of methane exceeds 1% 1. A high methane hazard is significant for coal mines in Poland.

In order to facilitate the evaluation of noise hazard at the work place in coal mines attempts have been made to apply TTS measurements [2], [3], [4].

Making use of this method the authors were fully aware of the fact that TTS measurements carried out in full--scale industrial conditions can assure only a tentative hazard evaluation. The necessity to find some method of evaluating the noise hazard in conditions when the danger of methane explosions is continuously rising has made us take up these investigations.

CHARACTERISTIC OF THE ACOUSTIC CLIMATE.

For the purpose of taking measurements five sets of test stands have been selected, all of them displaying the

most characteristic noise parameters. In all the investigated cases the noise was characterized by considerable changeability in time, its dynamics amounting to more than 20dB. An example of a time study for the test stands of set II is to be seen in Fig.1.

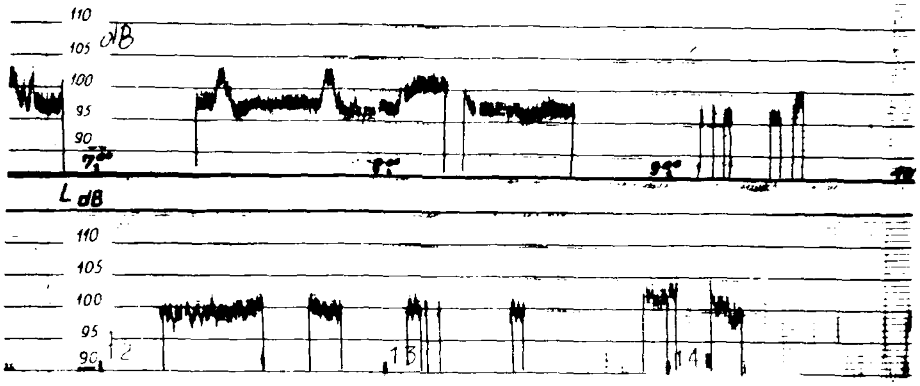

Fig.1- An example of a time history for the test stands of set II.

In the case of each set of test stands dosimetric measurements were taken within seven hours, and the equivalent levels of noise were dtermined.

Set I- L_{eq}= 90 dB(A) , set II - L_{eq}= 93 dB(A) ,
set III - L_{eq}= 95 dB(A), set IV - L_{eq}= 98 dB(A),
set V - L_{eq}= 105 dB(A).

These equivalent levels were determined as mean values of the levels varying within the time in which TTS measurements were carried out. The noise spectra of all the sets of test stands displayed a preponderance of medium frequencies (400- to 2000 Hz).

CHARACTERISTICS OF THE TESTED POPULATION.

128 men ,aged 25 to 32, were chosen to be tested at their work places in the course of 5 to 6 years. All of them had to undergo otological examinations of their hearing power as well as detailed audiometric tests. Further tests

were carried out on those, whose audiogram did not show in any frequency that was tested a loss of more than 10 dB, the difference between the left ear and the right one not exceeding 5 dB. These tests comprised 24 persons in set I, 24 in set II, 26 in set III, 24 in set IV and 20 in set V. The latter number is so small due to the fact that only few people were employed in places with a high value of L_{eq} = =105 dB(A), who according to the criteria given above would prove to possess a normal sense of hearing.

THE METHOD OF TTS INVESTIGATIONS.

TTS measurements were taken by means of a specially constructed audiometer fed by a battery (Fig.2). This audiometer generated signals at three frequencies, viz. 500, 1000, 2000 Hz, the sound pressure level ranging from 10 to 80 dB in steps 5 dB. The audiometric zero was fixed in compliance with the ISO standard. The signal was transmitted by TDH-39 ear-phones mounted in PMX 50/10 cushions.

TTS measurements were taken before the employees started their work and about 3 to 5 minutes after they had been exposed for 7 hours or so to the effects of noise at places were the sound level of the acoustic background did not exceed 40 dB(A). Every day only one or two workers were subjected to TTS tests. Measurements were taken successively at the frequencies 500, 1000, and 2000 Hz, the test at 500 Hz being repeated once again. The TTS was determined for only one ear (the right one). The tested person had to signalize the reception of the signal by pressing a button. The lapse of time between the termination of the exposure and the cessation of the audiometric measurement amounted on the average to 3- 5 minutes.

Before the investigations proper could be started, instruc-tional tests were carried out in order to inform the partakers about the way in which the tests should be performed, and also to provide some practice for the investigating staff. Next the investigations proper were commenced, each test being carried out twice on different days. Most of the tested persons proved to display only small scatters of results obtained on two successive days, which equalled the accuracy of the measurement (5 dB).

RESULTS

Figs. 3 - 7 represent the results of TTS measurements for five groups of tested workers. The diagrams include test results for each of the tested frequency ; the full line denotes the mean value whereas the broken lines represent the

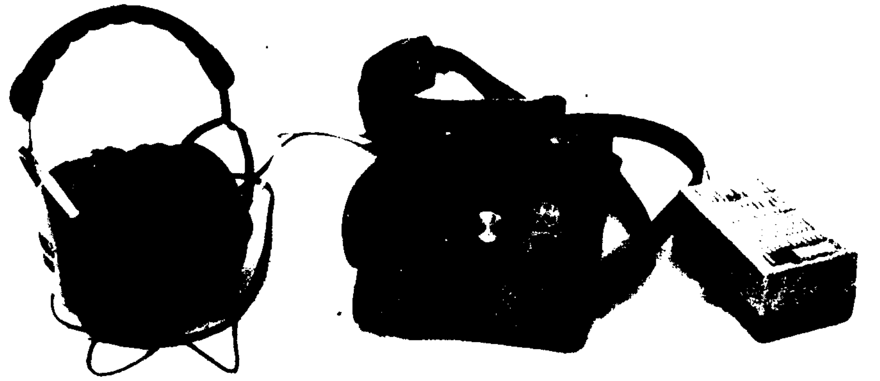

Fig. 2 - The specially constructed audiometer for TTS measurements.

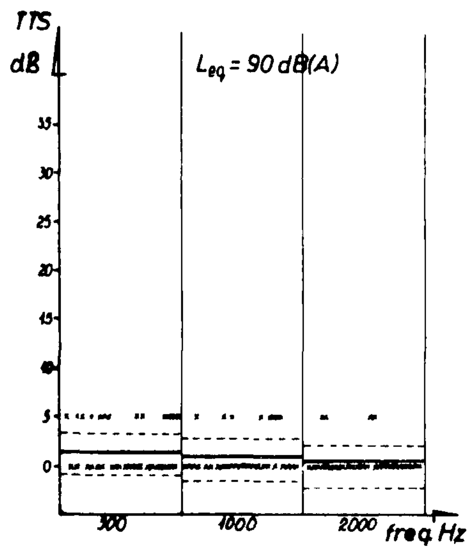

Fig. 3 - TTS for set I
L_{eq} 90 dB(A).

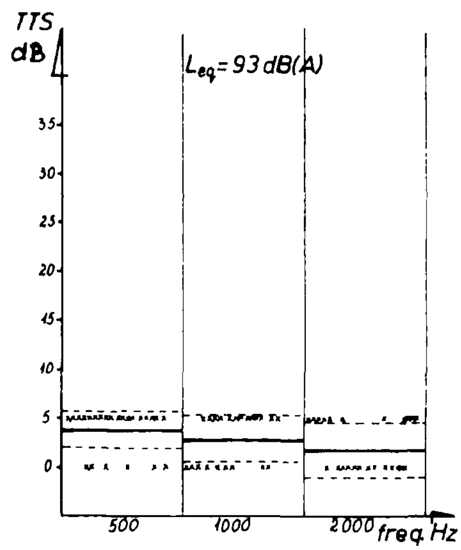

Fig. 4 - TTS for set II
L_{eq} 93 dB(A).

They also want to thank Mr Tadeusz Rabsztyn, M.Sc(Eng.), for constructing a special audiometer, which was applied in these investigations, as well as Mr Wojciech Beblo, M.Sc., for carrying out the statistical calculationns, and Mrs Irena Kubik, Mrs. Grażyna Jaroń and Mrs. Helena Rybak for their assistance in the elaboration of the test results and graphical preparation of this paper.

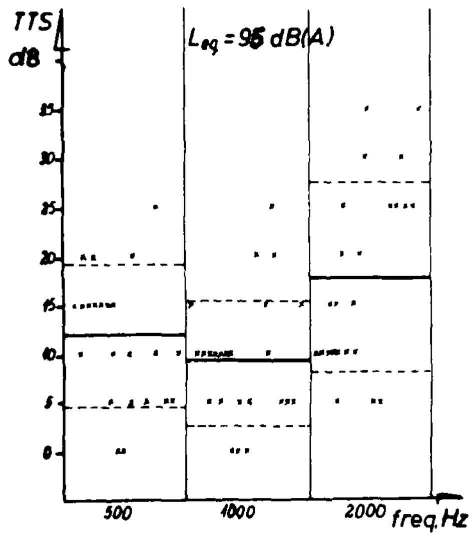

Fig.5 - TTS for set III
L_{eq} 95 dB(A).

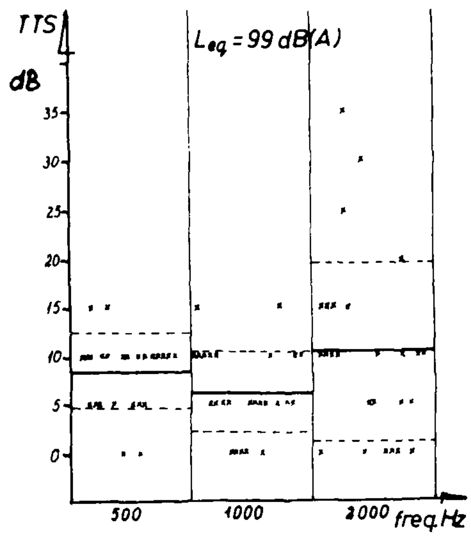

Fig.6- TTS for set IV
L_{eq} 98 dB(A).

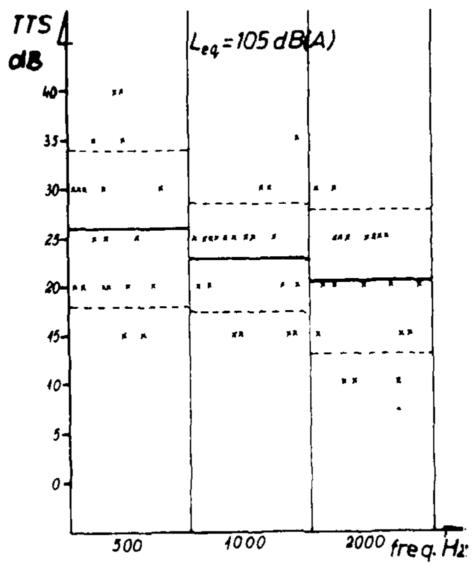

Fig.7 - TTS for set V
L_{eq} 105 dB(A).

the standard deviation $\pm\sigma$ from the mean value.

The numerical values have been gathered in Table I.

Table I

Set No.	Population	L_{eq} dB(A)	$TTS_{av} \pm \sigma$ 500 Hz	1000 Hz	2000 Hz
I	34	90	1,91 ± 2,46	1,32 ± 2,24	0,59 ± 1,64
II	24	93	3,75 ± 2,21	3,01 ± 2,45	2,29 ± 2,54
III	26	95	8,08 ± 3,76	6,35 ± 4,37	10,38 ± 9,27
IV	24	98	12,28 ± 7,52	9,38 ± 6,48	17,71 ± 9,55
V	20	105	26,25 ± 7,59	23,0 ± 5,48	20,5 ± 6,26

In order to determine the dependence of the TTS value on the equivalent level L_{eq} the mean values gathered in Table I were analysed regressively, by means of the method of least squares, assuming that the relation of TTS and L_{eq} takes the following shape:

$$L_{eq} = a \cdot (TTS)^{b}$$

The calculations which were carried out have made it possible to determine the curve equation as well as the correlation factor r_{xy}.

for f_1 - 500 Hz $L_{eq} = 86{,}08 \cdot (TTS)^{0{,}05582}$ $r_{xy} = 0{,}971$
for f_2 - 1000 Hz $L_{eq} = 87{,}85 \cdot (TTS)^{0{,}05216}$ $r_{xy} = 0{,}974$
for f_3 - 2000 Hz $L_{eq} = 90{,}81 \cdot (TTS)^{0{,}03305}$ $r_{xy} = 0{,}861$

Fig.8 represents the diagrams of the aforesaid relations. The position of the experimentally determined points concerning the respective frequencies has been indicated, too.

The calculated values of the factor r_{xy} indicate a good correlation of L_{eq} and TTS. Even in the case of the frequency 2000 Hz the value of the correlation factor is greater than 0,7 , so that the determined interdependence may be generally considered to be correct.

If we analyse the dispersion of the measuring results presented in Figs.3 to 7, particularly for the higher values of the equivalent value L_{eq} = 95 dB(A), 98 dB(A), we notice a particularly large scatter of results measured at the

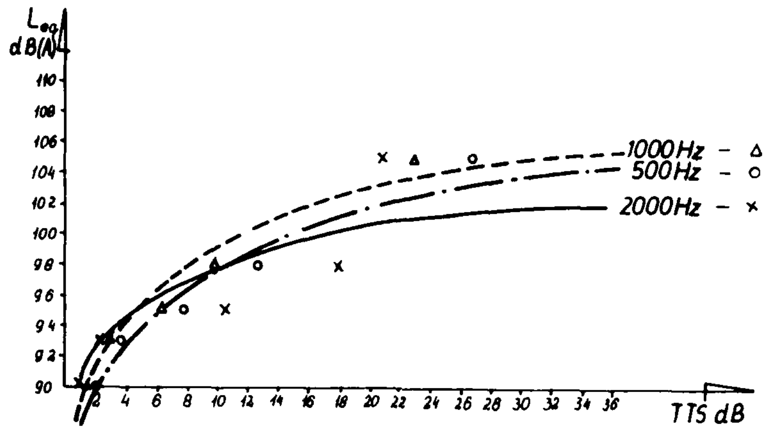

Fig. 8 - Diagrams representing the relation L_{eq} f(TTS).

frequency 2000 Hz, $\sigma \pm 9$ dB. The intersection of the curve representing the relation $L_{eq} = f(TTS)$ for the frequency 2000 Hz with the curves determined for the frequencies 1000 and 500 Hz is questioneable, too.

An attempt to explain this effect revealed that the measuring results are influenced by the position of the ear-phone and the sealing cushion in relation to the acoustic external meatus, in particular by leakages at the contact surface of the ear-phone cushion and the skull. In spite of the comparatively high value of the correlation factor $r_{xy} = 0,861$, the interpretation of the measuring results concerning the frequency 2000 Hz is controversial.

CONCLUSIONS.

Measurements of TTS within 3 to 5 minutes from the cessation of noise exposure, which were carried out in full-scale industrial conditions, have made it possible to evaluate the equivalent sound level in which the tested persons had been abiding. The obtained results show that the accuracy of estimation depends on the number of persons that had been tested. In the author's opinion at least 10 workers should

be subjected to such investgations.

When this proposed method of evaluating the noise hazard by means of TTS measurements is applied,people with a normal audiologically checked hearing power ought to be selected.

In industrial conditions audiometric measurements should rather be carried out at lower frequencies (500 Hz,1000 Hz), because then random errors can be avoided.Although TTS measurements at higher frequencies yield - according to several authors [3] - higher TTS values,they encumbered with considerable errors in the case when the tested workers are exposed to the same level of noise ; these errors are due to the not identical position of the ear-phone in relation to the acoustic meatus.

The results presented in Fig.8 - concern noise with a prevalence of medium frequencies (400 to 2000 Hz).According to literature the TTS values depend on the noise spectrum[3]. It has been considered to determine the relation $L_{eq} = f(TTS)$ for noise spectra according to Waugh's classification[5]. This would make it possible to apply this method for evaluation of the efficiency of individual ear protectors,as they are used in real industrial conditions.

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ACKNOWLEDGMENTS.

The authors want to express their gratitude to the Management of the Hard-coal Mine "Staszic"in Katowice for their permission to perform long term investigations,which must have been rather troubelsome for normal organization of work.

SERIAL CHANGES IN AUDITORY THRESHOLDS FROM 8 TO 18 YEARS IN RELATION TO ENVIRONMENTAL NOISE EXPOSURE

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Children may require special consideration in regard to environmental noise. A loss of hearing sensitivity may have more effect on function than in an adult because it may lead to a learning disability. Despite its importance, there have been few effective studies of hearing sensitivity in children in relation to noise exposure. It is not clear whether noise exposure is more likely to cause temporary threshold shifts in children than in adults. Some data indicate a greater sensitivity in children, in agreement with histological studies of animals (Jauhiainen et al., 1972; Bock and Saunders, 1977; Dodson et al., 1978; Lenoir and Pujol, 1980). Others have suggested the young are less susceptible than adults but recover more slowly (Ward et al., 1958; Wagemann, 1967; Hétu et al., 1977).

Cross-sectional United States National surveys provide circumstantial evidence that adolescents may be exposed to hazardous levels of noise (Glorig and Roberts, 1965; Roberts and Huber, 1970; Roberts and Ahuja, 1975). These surveys show little sex difference in sensitivity at 11 years but, in youths and young adults, the hearing sensitivity of males

is less than that of females at 4 kHz. Permanent shifts due to noise are noted in boys aged 16 to 18 years with firearms, farm machinery and music as common sources (Weber et al., 1967; Litke, 1971; Hanson and Fern, 1975).

MATERIAL AND METHODS

The findings to be presented are from analyses of data, recorded each six months, for 270 children aged 6 to 18 years. At the end of this 6-year study, 97.5% of the participants were still active. These children of middle socioeconomic status, lived in Ohio and were not selected because of any recognized disease or disorder. Data from nine children with chronic auditory problems have not been analyzed. Temporary pathological changes that could affect test results were present in other participants at 52 examinations. The data for these examinations have been used only in analyses related to significant threshold shifts. Details of the methodology are available (Roche et al., 1982).

RESULTS

Examination Effects. Serial threshold data may be affected by familiarity with the test environment, knowledge of test strategies, and changes in motivation. Also, noise exposure may alter if the study leads to increased awareness that noise might reduce hearing sensitivity. The relevant literature is restricted to adults in whom Ward (1957) reported examination effects only at 0.5 kHz in rapidly repeated examinations. Examination effects of about 1 dB/examination for annual examinations have been reported, but possible age effects were not excluded (Zwislocki et al., 1958; Robinson et al., 1979; Royster et al., 1980). In the present analyses, data from all examinations were used to establish the ordered number of each examination but data recorded when pathological conditions were present were excluded. Regressions were performed with thresholds as dependent variables; the independent variables were examination order and corresponding age. The coefficients for examination order can be interpreted as examination effects (dB change per examination), adjusted for age. There were significant linear examination and age effects for each sex and test frequency ($p<.05$) but there were no significant higher

order effects (Table 1). After removing age effects, the mean slopes of thresholds against examination order have significant ($p<.01$) negative values, indicating thresholds decrease with order. The rate of decrease is larger at 4 and 6 kHz than at lower test frequencies. The cumulative examination effects for eight serial examinations were about 3 dB, at 0.5, 1, and 2 kHz and about 5 dB at 4 and 6 kHz. The root mean square errors (measures of intersubject variability, dB) tend to increase with frequency after examination and age effects have been removed. The recorded data were adjusted for these examination effects before further analyses were made.

Selected plots of mean thresholds (4 kHz) with their standard errors for the left ears of boys and the right ears of girls are shown in Figure 1. These data, which have been corrected for examination effects, show hearing sensitivity tends to be better in boys than girls until 14 years but not at older ages. These means are a few dB lower than the corresponding values from U. S. National surveys.

Table 1. Examination and age effects and root mean square error from regression analyses after pooling data for both sexes and both ears.

Frequency (kHz)	Examination Effects (dB/examination) Mean	s.e.	Age Effects (dB/year) Mean	s.e.	Root Mean Square Error (dB)
0.5	-0.38	0.09	-0.58	0.07	6.66
1	-0.30	0.09	-0.50	0.07	7.68
2	-0.37	0.09	-0.38	0.07	6.70
4	-0.60	0.10	-0.21	0.08	7.40
6	-0.72	0.10	-0.28	0.09	8.42

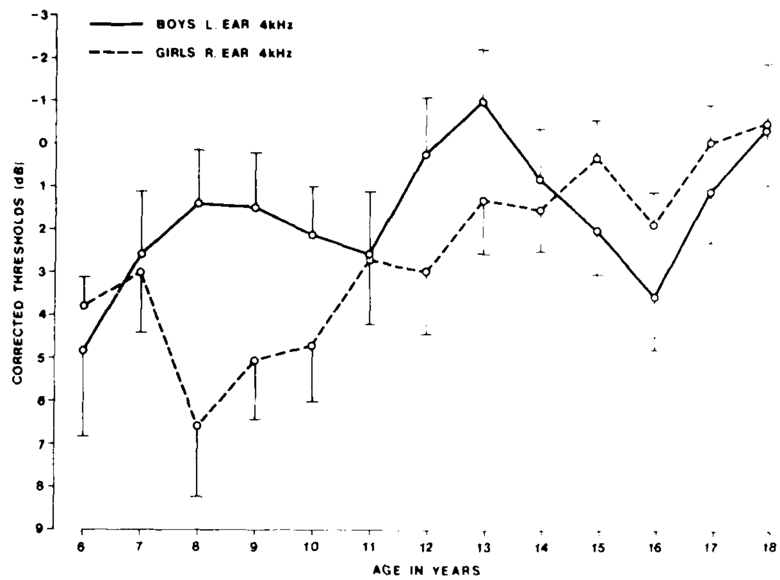

Fig. 1 - Means for thresholds (dB re ANSI-1969) with their standard errors, for boys (left ear) and girls (right ear) at 4 kHz.

Significant threshold shifts were analyzed by calculating sex-, ear-, and frequency-specific linear regressions of thresholds, adjusted for examination effects, on age for each participant who had 4 or more serial thresholds. Intercepts and slopes from these regressions were interpreted in relation to long-term threshold shifts.

There are no significant differences between mean intercepts among frequencies in the boys but in the girls those for 0.5, 4, and 6 kHz are significantly higher ($p<.05$) than those for 1 and 2 kHz (Table 2). The mean intercepts for boys are significantly lower ($p<.05$) than those for the girls at 0.5 and 4 kHz. Most mean slopes (dB/year) are negative indicating that hearing sensitivity improves with age. These slopes differ significantly from zero ($p<.05$) in the girls only. There are

Table 2. Intercepts and slopes from regressions of thresholds on age for the right ears of children.

Frequency (kHz)	Intercepts (dB) Mean	s.d.	Slopes (dB year) Mean	s.d.
Boys (N = 112)				
0.5	3.4	24.3	-0.25	2.12
1	2.5	24.8	-0.24	2.26
2	-0.6	26.5	0.13	2.28
4	3.9	29.8	-0.06	2.31
6	2.4	31.6	0.13	2.27
Girls (N = 102)				
0.5	9.8	21.0	-0.81	1.53
1	4.8	17.1	-0.52	1.28
2	4.1	19.4	-0.40	1.51
4	12.9	25.8	-0.83	1.91
6	8.1	27.9	-0.42	1.95

eight boys among the 10 children with the largest positive slopes indicating large long-term threshold increases are more common in boys. The apparent factors were more often respiratory infections or allergies than exposure to noise.

The largest absolute residual from the regression line for each child was regarded as a short-term threshold shift. Many of these were small and not functionally significant but 77% were positive indicating non-randomness. The means of these short-term shifts (Table 3) do not differ significantly between the sexes, but they are larger ($p<.05$) at 6 kHz than at the other test frequencies. The shifts tend to decrease with age in each sex, and to occur slightly later in boys than girls. They have a significant tendency to occur at the same age for both ears and all frequencies tested. The largest short-term shifts exceeded 20 dB in eight

Table 3. Distribution statistics for short-term threshold shifts (residuals; dB) in the right ears of children.

Frequency (kHz)	Boys Mean	Boys s.d.	Girls Mean	Girls s.d.
0.5	3.5	5.1	2.9	4.6
1	2.7	4.2	3.3	5.1
2	2.3	3.5	3.6	4.8
4	4.0	5.3	3.6	4.9
6	4.5	6.2	4.7	6.4

participants. The ears of four of these children were partially obstructed with wax. One girl was only 6 years old at the examination in question, and these data may be less reliable than the data in general. A cause for the large shift was not apparent in three boys.

Noise Exposure. To protect the hearing sensitivity of children, it is important to identify their environmental noise sources and quantify the level and duration of the noise. Analyses were made of 151 sets of observations from children whose noise exposure levels were measured with Metrosonics dB 301 Metrologgers. These Metrologgers record four samples/second and compute and store an average noise level (L_{eq}) for each three-minute period up to a maximum of 480 periods (24 hours). Noise levels were sampled by a ceramic microphone with a sensitivity of -40 dB and a figured response that meets ANSI requirements. The microphone was attached near the participant's collar to sample noise similar to that entering the ears. The participant kept a diary of timed activities during noise recording that were coded into 189 activity categories, allocating one category to each 3-minute period. For the present analysis, the activities were grouped into the 23 categories of noise sources (Table 4).

Table 4. Sample size (N), mean log equivalent sound level ($L_{eq(t)}$) for duration, and 8-hour ($L_{eq(8)}$) for sound sources.

	Activities	Boys (N = 79)			Girls (N = 72)		
		N	($L_{eq(t)}$)	($L_{eq(8)}$)	N	($L_{eq(t)}$)	($L_{eq(8)}$)
A	Lawnmowers/combustion engines	7	88.1	80.9	--	--	--
A	School bus	14	86.4	75.1	16	81.6	69.0
A	School assembly/recess	28	84.7	75.2	31	81.7	71.9
A	Live music	19	84.1	75.7	30	82.8	73.1
B	School gymnastics classes	10	80.8	70.1	--	--	--
B	Small power tools	6	80.7	73.6	--	--	--
B	Walking to and from school	9	79.6	63.4	12	69.3	54.9
B	Sports/playground	30	76.6	67.9	20	76.5	66.4
B	School special classes	8	76.4	67.4	7	70.2	60.0
B	School miscellaneous	8	76.3	60.1	11	74.9	60.0
B	Vehicle	67	76.3	65.5	62	75.1	65.2
B	Home small appliances	41	76.0	63.7	49	73.3	61.8
B	Home miscellaneous	73	75.9	58.2	19	74.5	60.0
B	Outdoors	47	75.6	66.8	36	73.4	62.3
B	School normal classes	30	75.1	72.3	33	69.4	65.8
B	Home radio/T.V.	76	74.6	70.2	69	70.7	67.0
B	Shopping	29	74.0	64.1	31	71.3	61.3
B	Home conversation	72	73.7	67.0	71	72.1	66.0
C	Office	34	68.2	53.4	32	65.8	49.6
D	Sleep	79	57.0	57.9	72	53.8	54.5

A, B, C, and D are explained in the text.

The noise exposure data for each child were summarized by computing an ($L_{eq(t)}$) for each activity category (Table 4). This provides a measure of the noise level associated with a specific activity averaged over individuals without respect to duration. Also ($L_{eq(8)}$) was calculated to represent the noise level that, given over an 8-hour period, would have the same sound energy as that to which the children were exposed. The least common activities involved lawnmowers/combusion engines and small power tools. In addition, few girls participated in school gymnastics classes. The ranking of activities is similar by ($L_{eq(t)}$) or ($L_{eq(8)}$). Within four groupings of categories (A, B, C, and D), the L_{eq}s are similar but the means differ from one group to another. Girls have lower mean L_{eq}s than boys for almost every activity, but the differences are significant ($p<.05$) only for walking to and from school, school normal classes, home radio/T.V., and sleep.

In boys, lawnmowers/combustion engines, live music, school bus, and school assembly/recess are major noise sources. Each of these sources has an ($L_{eq(t)}$) > 80dB, and the average duration is from 0.5 to 2.1 hours per day in those exposed. These noise exposure data tend to decrease with age, except for live music for which the duration and noise level tend to increase with age.

The ($L_{eq(8)}$) values were converted into kilo Pascal squared persons (Kpa^2) and multiplied by the number of boys and of girls reporting exposure (Figure 2). The order of values is similar to those of Table 4. School assembly/recess is the most important noise source for boys accounting for 16% of the total sound energy. Live music accounts for [illegible] of the total sound energy for girls. The largest sex difference is for lawnmowers/combusion engines, for which boys are exposed to about [illegible] more energy than girls.

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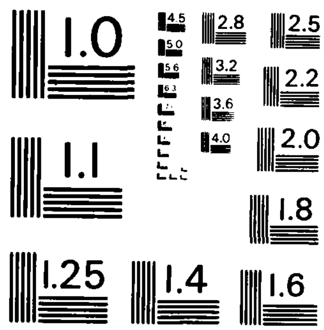

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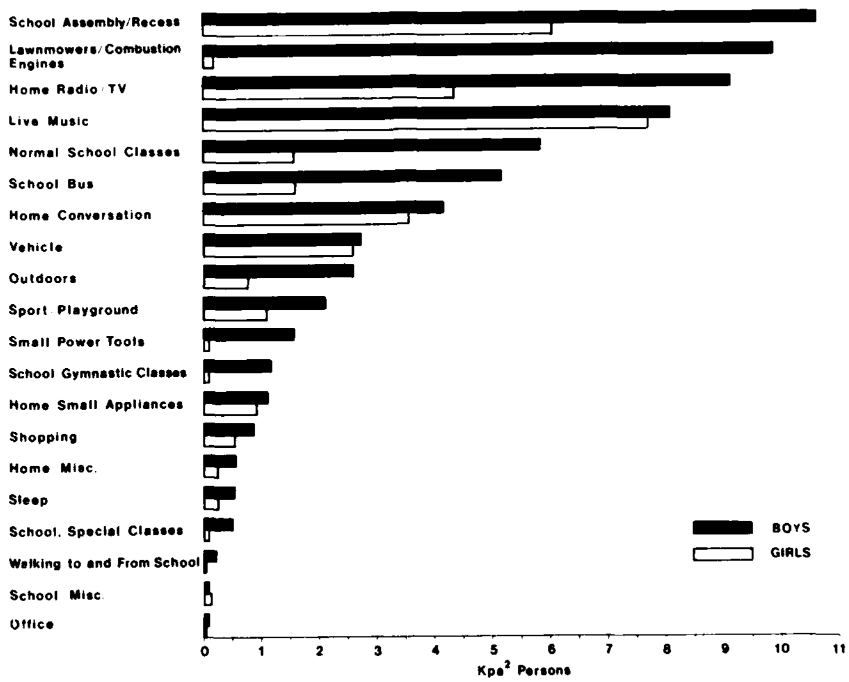

Fig. 2 - Kilo Pascals squared persons for noise categories in boys and girls.

It has been estimated that the average ($L_{eq(24)}$) for school children is about 77 dB (EPA, 1974; Von Gierke and Johnson, 1975), but there are few data other than those of Schori and McGatha (1978a, 1978b) who found a mean ($L_{eq(24)}$) of 76.2 dB for 10 children and Siervogel and associates (1982) who found ($L_{eq(24)}$) in the Fels sample as being 78-85 dB for boys and 76-83 dB for girls. Clearly, from the present study, many children are routinely exposed to levels above 79 dB, and some to noise levels above 85 dB which may be harmful. Further studies are required to allow estimates of noise exposure from activity diaries and to estimate exposures for groups at particular risk, for example, those living in

densely populated areas.

CONCLUSION

The data presented were selected from the total report for this study (Roche et al., 1982); a later report (Roche et al., in press) includes the original data. This study has shown adjustments should be made for examination effects before serial data are analyzed or judged and that many children are exposed to potentially harmful levels of environmental noise. The absence of decreases in hearing sensitivity with age in these children indicates that noise exposure, at the levels considered, might be harmful only if it extends over long periods.

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ACKNOWLEDGEMENT

This work was supported financially by the United States Air Force and the United States Environmental Protection Agency.

ON THE GROWTH AND DECAY OF ASYMPTOTIC THRESHOLD SHIFT IN HUMAN SUBJECTS.

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INTRODUCTION

Since 1970, much attention has been given to the temporary shifts in hearing threshold (TTS) induced by noise at moderate levels but of prolonged duration. Such TTS grows rapidly during the first few hours of exposure but soon approaches an asymptotic value (ATS) which is generally reached within 24 hours. When the exposure is terminated the recovery from ATS is comparatively slow. For this reason, measurements of ATS are thought to shed light on the potential long-term effects of occupational noise exposures of exceptional duration as well as chronic exposures to environmental noise (e.g. Johnson et al, 1975).

MATERIAL AND METHODS

The present work brings together ten sets of data from seven studies with groups of human subjects in which TTS was measured during exposure to steady noise for periods up to 48 hours and post-exposure for periods up to 72 hours. The purpose is to determine average values of ATS at the highly sensitive frequency of 4 kHz, as a function of sound level, and develop corresponding families of curves showing the average values of TTS during growth and decay.

Table I shows the sources of data, some measurement details and the symbols used in the figures which follow. As can be seen, six of the ten sets of data were obtained with broad-band "pink" noise (i.e. equal energy per octave) and four with octave bands of noise centred at 4 kHz. The method is based on the hypothesis that the TTS at 4 kHz due to pink noise

Table 1. Sources of data, details of measurements and key to symbols.

Author (Year)	Type of measurement (Author's figure number)	Number of male/ female subjects	Sound Level dB	Exposure Hours	Symbol
Johnson et al (1975)	Pink noise, TTS at 4 kHz (Fig. 2)	11 m	85 (A)	24	◇
		11 m	85 (A)	48	-◇-
Melnick (1975)	4 kHz OB noise, TTS at 4 kHz, 1 ear (Fig. 6)	7 m	80, 85	24	●
Ward (1975)	4 kHz OB noise, TTS at 4, 5.6 kHz (av), 2 ears (Figs. 2 and 3)	10	70	6	▼
		10	75	8	▼
		10	75	24	▲
		30	80	6, 8	▼
		10	80	24	▲
		10	85	7	▲
		5	85	2	▲
Johnson et al (1976)	Pink noise, TTS at 4 kHz, 1 ear (Fig. 2)	12 m	85 (A)	24	△
Nixon et al (1977)	Pink noise, TTS at 4 kHz, 1 ear (Fig. 6)	12 m	85 (A)	24	□
		12 m	85 (A)	48	-□-
Mills et al (1979)	4 kHz OB noise, TTS 3.5 - 6 kHz (varied), 1 ear (Figs. 2, 9)	4 m	75	24	■
		3 m,4 f	80	24	■
		7 f	83	24	■
Stephenson et al (1980)	Pink noise, TTS at 4 kHz, 1 ear (Fig. 2, Table III)	12 m	70, 75 80, 85, (A)	24	○

having an A-weighted level L_A is virtually indistinguishable from the TTS due to octave-band noise centred at 4 kHz and having an SPL 5 dB lower than L_A. In effect, this hypothesis implies that 1.5 octaves of the pink noise contributes to the TTS at 4 kHz.

RESULTS

The ten sets of data presented in Fig. 1 show the growth of TTS according to the studies listed in Table I. The five panels bring

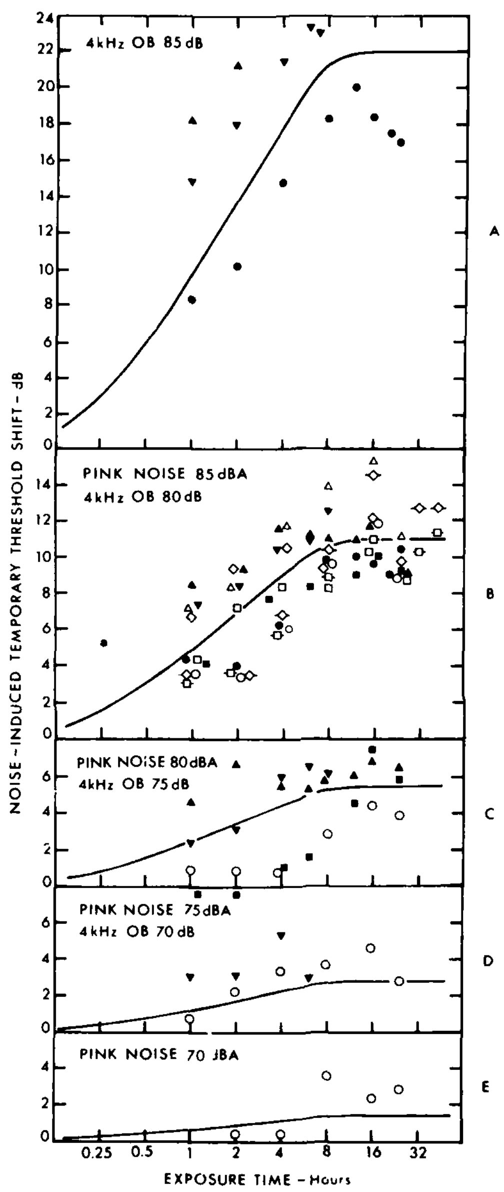

Fig. 1 - Experimental data from studies listed in Table I showing values of TTS during exposure. Smooth curves are based primarily on data in Panel B and ATS curve (solid line) presented in Fig. 2. Curves in Panels A, B, C and D are scaled from Panel B.

together the broadband and 4 kHz OB data in accordance with the principle enunciated earlier. A cursory examination of Panel B indicates that, at most exposure times, the solid points (4 kHz OB, 80 dB) do, indeed, belong to approximately the same statistical distributions as the open points (Pink Noise, 85 dB). Closer study indicates that there may be a tendency for TTS to grow more slowly with broad-band noise than with octave-band noise, while approaching the same asymptote. The differences between pairs of mean values at 1, 2 and 4 hours are, however, little more than 1 dB which is barely significant.

Figure 2, which is organized in the same manner as Fig. 1, shows the asymptotic values of TTS calculated from the same sets of data. Following Melnick (1975) and others, these values are in most cases averages of all measured values of TTS taken at exposure times equal to or greater than 8 hours. The largest value shown in Fig. 2 (25 dB) is, however, Ward's estimate of ATS in an experiment which terminated after two hours and the second highest (23.2 dB) is the average of his measurements at 6 and 7 hours. His lowest value (2.9 dB) is the final value in a six-hour experiment. For consistency, the six-hour values from Ward's 24-hour experiments have also been included in the calculations of ATS.

The average values of ATS from the six 85 dBA pink-noise experiments and for the four 80 dB octave-band experiments are almost indentical (11.0 dB and 10.4 dB respectively). Moreover, all ten values of ATS (overall mean: 10.75 dB) lie within the range 9.1 to 13.4 dB. This clustering of data clearly points to a target value in the vicinity of 11.0 dB at the 85 dBA/80 dB level. To accommodate the data at higher and lower levels it appears essential to choose a graph with considerable curvature. The following functions are shown in Fig. 2:-

$$S_a = 11 \times 2^{0.2(L_e - 85)} \text{ dB} \quad (\text{———}) \qquad (1)$$

$$S_a = 0.0651\ (L_e - 75)^2 \text{ dB} \quad (\text{—— ——}) \qquad (2)$$

$$S_a = 17 \log\left[1 + (I_e/I_c)\right] \text{ dB} \quad (\text{-------}) \qquad (3)$$

$$S_a = 20 \log\left[1 + (I_e/I_c)\right] \text{ dB} \quad (\text{— - —}) \qquad (4)$$

where I_e/I_c = antilog $[0.1\ (L_e - L_c)]$. In all four expressions, L_e is the A-weighted level of pink noise. It will be understood that, for 4 kHz OB noise, 5 dB must be added to the SPL to obtain the appropriate value of L_e. In functions (3) and (4), the values of L_c (79.6 dB and 80.9 dB, respectively) have been chosen to meet the target value of 11 dB at

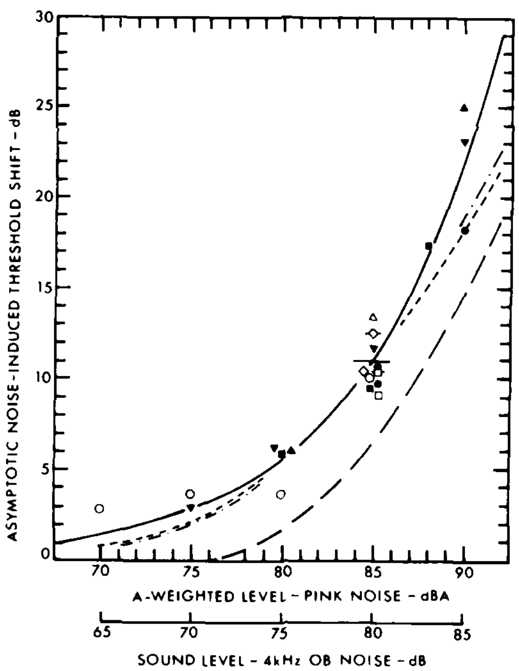

Fig. 2 - Experimental values of ATS derived from data presented in Fig. 1 (see also Mills, Table I). Graph lines show four mathematical functions discussed in text.

85 dBA/80 dB. The reference level of 85 dB serves the same purpose in Function (1).

Function (3) will be recognized as the expression used by Mills to fit the 4 kHz OB data. (Note that his value I_c is equivalent to an L_c of 79 dB.) Function (4) is mathematically identical with the theoretical expression given by Maslen (1983). Function (2) is the quadratic expression used in a new ISO document to calculate the median value of NIPTS at 4 kHz due to 40 years of occupational exposure at noise exposure level L_e (ISO, 1982). To bring this curve into coincidence with the others at the 85 dBA/80 dB level it would be necessary to choose a cut-off level of 72 instead of 75 dB.

Function (1) is very similar to one used by Thiessen (1976) in a Canadian criteria document to predict the development of NIPTS. It can be rewritten as the power law

$$S_a = 38.1\ (P_e/P_o)^{1.2}\ \text{dB} \qquad (5)$$

where P_e is the rms sound pressure corresponding to L_e and P_o is the reference pressure of 1 Pa (SPL: 94 dB). In choosing between the four functions it is necessary to rely on the data at higher and lower levels. Clearly these lack the statistical significance of the pivotal point on the graph. Functions (1), (3) and (4), and Function (2) with a 72 dB cut-off, fit the next point on the graph (80 dBA/75 dB) equally well. Functions (3) and (4) appear to be inadequate at the highest level (90 dBA/85 dB). Function (2), when shifted by 3 dB, is acceptable at the highest level but fails to take account of the data at the lowest levels (70 dBA/65 dB and 75 dBA/70 dB). Only Function (1) seems to do justice to the data at both the highest and lowest levels not withstanding the uncertainty inherent in the spread of the data. This expression implies

that, for moderate levels of pink noise and 4 kHz OB noise, the ATS at 4 kHz doubles with each 5 dB increase in level.

The smooth growth curve shown in Panel B of Fig. 1 is empirical. The simple exponential function

$$S = 11 \left[1 - \exp(-t/\tau)\right], \tag{6}$$

where $\tau = 0.35$ hours, has a slightly steeper rise than the expir curve but would serve almost equally well (c.f. Mills et al, 1979). I ne interest of simplicity the growth curves for the other sound leve (Panels A, C, D and E) are taken from Panel B with simple scaling factors of 2, 0.5, 0.25 and 0.125, respectively. Within the limits set by the spread of data, these curves appear to fit the experimental data reasonably well. Perhaps the rise in Panels A and D should be shifted towards lower exposure times. If so, movement in the opposite direction would be indicated in Panel C.

The data presented in Fig. 3 show the decay of TTS according to the ten studies listed in Table I. This figure is the counterpart of Fig. 1. Referring to Panel B it is apparent that, during recovery as during exposure, the solid points (4 kHz OB, 80 dB) belong to approximately the same distributions as the full complement of open points (Pink Noise, 85 dBA). This is certainly indicated by the mean values as shown in Table II.

It is also apparent that the mean TTS during recovery does not decay exponentially with time. Instead, it falls rapidly from the asymptotic value to a plateau which is attained at approximately 0.5 hours and maintained until nearly 4 hours. The smooth decay curve shown in Panel B of Fig. 3 is of this form. Though it is empirical, it could probably be matched by a function of the form

$$S = S_1 \exp(-t/\tau_1) + S_2 \exp(-t/\tau_2) \tag{7}$$

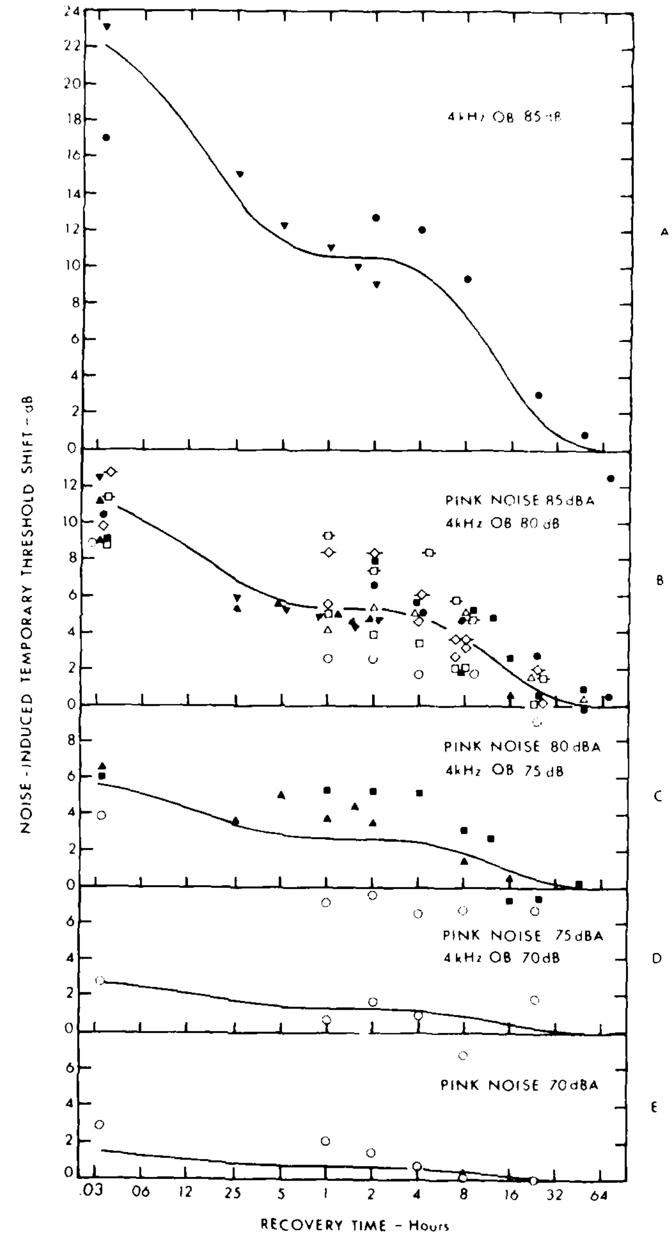

Fig. 3 - Experimental values of TTS during recovery. Curves are empirical (see text).

Table II. Average values of ATS and of TTS during recovery for data presented in Panel B of Fig. 3.

Noise type	ATS	TTS at various times (hours)						
		0.03	1	2	4	8	24	48
Pink 85 dBA	11.00 dB	12.3	5.8	5.5	4.9	3.3	1.0	0.3 dB
4 kHz OB 80 dB SPL	10.41 dB	10.3	5.0	5.9	5.3	3.9	(0.5)	(0.3)dB
Both	10.75 dB	11.5	5.6	5.7	5.0	3.5	1.0	0.3 dB

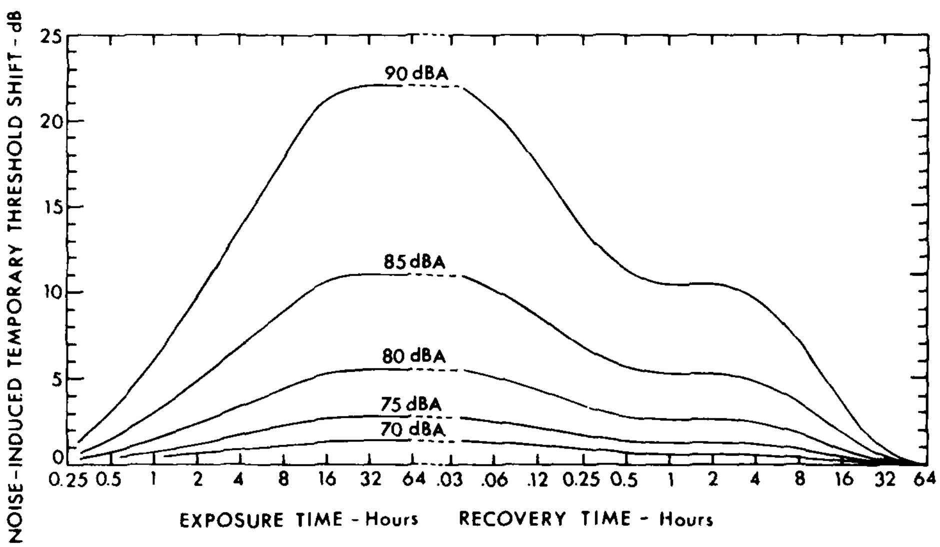

Fig. 4 - Families of fitted curves representing the average growth of TTS at 4 kHz in human subjects exposed to various levels of pink noise (equal energy per octave) and the recovery from asymptotic threshold shift.

where τ_1 and τ_2 are approximately 0.1 and 8 hours, respectively.

As in Fig. 1, the decay curves for the other sound levels (Panels A, C, D and E) are taken from Panel B with scaling factors of 2, 0.5, 0.25 and 0.125, respectively. Within the generous limits set by the spread of data, these curves also appear to be in reasonable agreement with the data.

For convenience, Fig. 4 brings together, as connected families, the fitted curves from Figs. 1 and 3. The curves are taken to represent the average amounts of TTS at 4 kHz induced in human subjects who are exposed to pink noise at the levels indicated, or 4 kHz OB noise at SPLs 5 dB lower, for periods of 24 hours or more. They indicate that approximately 25% of the recovery from ATS occurs within 10 minutes, approximately 75% within 12 hours and approximately 90% within 24 hours.

The purpose of two of the pink-noise studies listed in Table I (Johnson et al, 1975 and Nixon et al, 1977) was to determine whether the

Table III. Average values of ATS and of TTS during recovery for data presented in Panel B of Fig. 3. (Parentheses indicate single set of data only).

Noise exposure	Symbols	ATS	TTS at various times (hours)					
			0.03	1	2	4	8	24
48 hours Pink Noise 85 dBA	◇ ⌑	11.5 dB	12.1	8.8	7.9	7.2	4.2	1.8 dB
24 hours Pink Noise 85 dBA	△ □ ○	10.8 dB	9.3	4.3	3.9	3.7	2.9	0.28 dB
24 hours 4 kHz OB 80 dB SPL	● ■ ▲ ▼	10.0 dB	9.5	(5.5)	7.1	4.8	3.9	1.6 dB

recovery from TTS was dependent on exposure duration. Close scrutiny of the data presented in Panel B of Fig. 3 tends to support the authors' conclusion that exposures of 48 hours' duration produce greater amounts of TTS during recovery than do exposures of 24 hours duration. Table III shows the average values of TTS during recovery following exposure to pink

noise for 48 hours (line 1), Pink Noise for 24 hours (line 2) and 4 kHz OB noise for 24 hours (line 3). The differences seem to indicate that the plateaux in the recovery curves could be placed at 70% of ATS for 48-hour pink noise, 35% of ATS for 24-hour pink noise and 55% of ATS for 24-hour 4 kHz OB noise. The data are, however, so sparse and scattered that this interpretation cannot yet be advanced with great confidence. More experimental work with human subjects is clearly needed including work in which the exposures extend beyond 48 hours.

CONCLUSION

A synthesis of data from seven studies shows that the growth of TTS at 4 kHz in human subjects exposed to pink noise of prolonged duration at any moderate level L_A, is virtually indistinguishable from the TTS due to 4 kHz octave band noise having an SPL 5 dB lower than L_A. Smooth curves fitting the distributions of data are nearly exponential in form. The synthesis indicates that the average asymptotic level doubles for each 5 dB increment in level over the range 70-90 dBA. For pink noise the average ATS at 85 dBA is 11 dB. The asymptote is approached at 8 hours and is attained within 16 hours. The decay from asymptotic threshold shift (ATS) reaches a plateau which is attained at approximately 0.5 hours post-exposure and maintained until nearly 4 hours. According to curves fitted to the full complement of data, approximately 25% of the recovery from ATS occurs within 10 minutes, 50% within one hour, 75% within 12 hours and 90% within 24 hours. Close scrutiny of the data indicates that the level of the plateau during recovery may be substantially greater for 48-hour exposures to pink noise than for 24-hour exposures (perhaps 70% of ATS compared with 35%).

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PROPOSAL FOR A SCIENTIFIC PROGRAM

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The direction in which future research should be pointed has changed very little, in the opinion of our Team, since our last meeting. The determination of the appropriate measure of exposure, especially in the case of impact and impulse noise, remains an urgent area for intensive activity. There is ever-increasing evidence that the 8-hour equivalent level is not correct for all exposures; however, it is likely that it will continue to be widely employed because it is reasonably easy to measure or calculate. Therefore experiments must be undertaken to determine correction factors to be applied in the case of wide ranges of specific temporal patterns of exposure, specific impact spectra and peak levels, and specific levels and durations of impulse noise. Obviously these experiments must be done with animal models, and will require many years of effort. Cooperative work by several laboratories could shorten the time required to gather enough data to seek general principles, but of course this would involve prior agreement on the most practical animal model or models, the method of measurement or calculation of exposure, and the index or indices of damage to be used by all laboratories. If such agreement could be obtained, this research would have highest priority.

On the question of high-frequency audiometry and its possible use as a susceptibility index--i.e., using a change of threshold at high frequencies as a precursor of damage at the more traditional 4 and 6 kHz--the conflicting and inconclusive evidence from cross-sectional studies, both in the literature and presented here, makes it clear that the issue can be resolved only by longitudinal studies of workers with industrial exposures between 80 and 90 dBA in equivalent level and of appropriate controls. This population is also the only one on whom other possible susceptibility tests can be validated. High priority should therefore be assigned to initiation of such longitudinal studies.

Other areas in which additional work seems, in the Team's opinion, to be both desirable and feasible include the following:

(1) Development of norms for high-frequency audiometry, not only for young persons (audiometric zero) but also for males and females, not exposed to industrial noise, of increasing age.

(2) Study of the relation between otological abnormalities and apparent susceptibility to noise-induced hearing loss.

(3) Determination of the reasons why some ear protectors afford more consistent protection than others.

(4) Development of standard procedures for evaluating nonlinear ear protectors.

(5) Studies of individually-tailored hearing aids designed specifically for persons with noise-induced hearing loss.

Poster Session

THE IMPULSE NOISE EXPOSURE AND THE EFFECT OF PROTECTORS IN ARMY

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INTRODUCTION

Noise exposure during military service is almost exclusively of the impulse type. In many articles (Coles et al., 1977, Kryter and Carwiter, 1966) the hearing damage caused[1] by the firearms' impulse has been discussed but the forecasts of the risk is unknown to short exposure. Also the knowledge of the effects of ear protectors and their use is scanty.

The purpose of this study was to investigate the exposure to impulse noise in army, to establish epidemiologic risk and to measure attenuation of noise protectors for impulse noise.

METHOD AND MATERIALS

The material for the study comprised 536 conscripts, whose average age was 19,7 years (17-29 years) of these 351 were checked again after 8 or 11 months of military service.

Hearing measurements were made at the Military Hospital I with Madsen OB-60 audiometer at frequencies ranging from 0,25-8 kHz and calibrated with ISO 1964. The limit of normal hearing was taken as 20 dB. Questionnaires were used in the anamnestic sample.

In the exposure measurements the following parameters were defined: sound presure's peak value, duration of the impulse, frequency spectrum, number and density of impulses. The noise reduction of ear and protectors were made by using objective method (ISO R 209).

The measurement apparatus used was made up of the following instruments: impulse Precision Sound Level Meter (Brüel & Kjaer 2209), 1/8- and 1/4-inch pressure microphone (Brüel & Kjaer 4136, 4138), sound level calibrator (Brüel & Kjaer 4230), tape recorders (Kudelski Nagra IV SJ and Brüel & Kjaer 7003), analysers (HP 5420A and Brüel & Kjaer 1615), impulse recorders (Brüel & Kjaer 7502 and Datalab DL 905 Transient Recorder), storage oscilloscope (Philips PM 3234).

RESULTS

During the period of military service, the most important sources of impulse noise are the assault rifle 158-161 dB and rifle 158-161 dB. In addition, the conscripts practised with the light (165-180 dB) and heavy (172-175 dB) bazooka and mortar (166-176 dB). Those serving in the artillery had to fire different kinds of guns whose values ranged from 154 dB to 177 dB.

In many impulses, brief reflection impulses, with peak values of more than 10 dB smaller, could be seen 50-200 ms after the initial impulse. T_B values were naturally dependent on the acoustic properties of the surroundings in addition to those of the weapon and varied from 20-200 ms. The differences in L_p measured at the left or right ear were 2-6 dB with the firing position influencing the difference considerably. The noise from neighbouring weapons in covered ranges was important as its peak value at a distance of 1-2 metres had decreased by only 3-6 dB.

During 8 months' service each recruit was exposed, on average, to 100-300 assault rifle rounds under cover, 100-150 blank assault rifle rounds in the field and 10-20 sub-machine gun shots, depending on their unit. The number of rounds for those serving 11 months was almost doubled.

Hearing deterioration (over 10 dB) was confirmed in 52 of the 351 conscripts studied; 33 (9.4 %) had a 20 dB, or greater shift. On the hearing deteriorations, (19.2 %) in the right ear, 36 (69.2 %) in the left, and 6 (11.5 %) in both ears.

The noise reduction of four ear cups was measured (Silenta Super and Z Silenta Mil). In table 1 are shown the attenuation values of the tested ear cups for continuous and impulse noise. The impulse noise measurements were done under the roof, using impulse noise of automatic rifle.

Table 1

	Reduction for continuous noise					Average reduction for impulse noise (0°)	
	125Hz	500Hz	1kHz	2kHz	4kHz	A	lin
Cup I (Silenta Super)	16	26,5	38	45	41	35-40	30-36
Cup II (Silenta Mil)	10	22,5	34	36	42,5	33-36	30-34

CONCLUSION

Relatively many hearing deteriorations occurred during the period of military service (in 14.8 %). and those serving 11 months developed relatively more. The most important source of noise was the assault rifle; average 200-450 rounds/man during an 8-month period. The peak values of all weapons exceeded 130-150 dB, which is generally held to be the critical impulse noise peak value. Clearly, more shifts were confirmed in the left ear, presumably due to the firing position and the protection given to the right ear by the head.

The risk of hearing damage can be diminished either by technical, structural preventive methods or by the use of individual hearing protectors.

The impulse noise reduction of the tested ear cups were 26-37 dB(A) as the difference of Lpeak-values and 24-36 dB without A-filter. The greater the volume of the cup the better the reduction was (3-5 dB). There was no substantial difference between the reduction for continuous and for impulse noise.

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THE STUDY OF OCCUPATIONAL HEARING LOSSES IN RELATION TO CONFINED SPACES

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Occupational loss of hearing is becoming a pressing, topical problem, since workers of many kinds are required to operate in very noisy surroundings. One of the main objectives when assessing the noise in confined spaces is determination of the risk of hearing damage caused by protracted exposure to the high sound pressure levels encountered in work environments. Irreversible occupational disease is also dependent on frequency, and is partly linked to a certain degree of individual sensitivity.

Audiometry tracings show a characteristic dip for this pathology at 4 KHz.

Recent advances in the study of ambient noise assessment make it legitimate to enquire whether the methods most commonly employed are really effective when applied with a view to protecting the hearing function.

Brammer and Piercy (1977) suggest that sound pressure values should be determined at the concha to cut out discordances due to directional sources.

Weinrich (1981) has extended the experiments conducted with the Kemar manikin to the deformations created by interaction between the sound field and the manikin itself. The importance of this question is linked to the

need to work out a measuring method giving results that can be reproduced as far as possible. Another feature to which attention can be drawn is that of the rules now most widely used throughout the world. At present, there is no universally accepted standard for the acceptability of exposure to noise.

ISO recommendation 1999 covers the field of stationary noises in keeping with the still controversial equal energy principle. It is defective, however, with regard to impulse and impact noises.

The CHABA standard proposes hearing protection for 95% of persons exposed to the noise of firearms. It is clear that this criterion does not satisfy the needs raised by impact noise in industry. Coles & Rice (1970) have put forward some corrections to be made to this criterion, indicating that they feel that it could also be applicable to some sectors of industry.

As matters now stand, there are two main risk criteria for exposure to impulse and impact noise. These have been issued in the form of standards by the OSHA (Occupational Safety and Health Administration, USA) and the BOHS (British Occupational Hygiene Society, UK) respectively. The former has an exchange rate q = 5, the second q = 3. The BOHS standard with the method of Martin and Athersley is unsuitable for routine practice, since the instruments required are complicated.

Even though criteria have been advanced for the evaluation of impact and impulse noise, attention must be directed to the fact that there is still no clear definition of what is meant by an "impulse" in acoustics.

The criteria mentioned agree in using the A weighting filter. Its validity, however, is now being questioned by many researchers.

Brüel (1975) was one of the first to stress both the lack of a clear definition of impulse noise in acoustics and the indiscriminate use of the A filter. He suggested that the D filter (confined to the NEF standard) should be extended to industrial noise.

Wyk (1980) has published the results obtained by study group B of ISO

Committee TC/43/SC 1 (round robin test). Two conclusion were drawn:

1) disagreement between subjective feelings and filters A,D. Filter D seemed to be more appropriate for high intensity levels. Filter A, which is most commonly employed, was less suitable.

2) The most suitable indices of sound sensation evaluation appeared to be those of Zuieker and Stevens.

Kuhn (1977) has drawn attention to the transference function that exists between the diffused field and the eardrum. This function shows that the function of the tympanum can be 15 dB greater than the pressure of the field at 2.7 kHz. This amplification may contribute to the hearing loss observed at 4 kHz and checked on workers exposed to noise.

The writers of this paper presented a report at the 3rd National Congress of the Italian Industrial Hygienists Association based on the matters expressed above. They used recordings taken in 13 factories after filtering sounds recorded in dB lin through A and D weighting circuits to show that there is close agreement between sound pressure levels expressed in dB (B) and those calculated with the Stevens method (Mark VII), whereas this was not the case for values in dB (A).

Conclusions

It is felt that an evaluation standard for the risk of occupational hearing loss covering all types of sound encountered in industrial environments should be drawn up. This standard should emerge from future research aimed at clarifying certain points that are still controversial, namely:

1) the validity or otherwise of the equal energy principle;

2) the exact meaning of the word "impulse" in acoustics;

3) construction of a weighting filter differing from that used so far, namely the A filter, and taking account of the geater sensitivity of the human hearing apparatus in the 2.7 - 3 kHz range;

4) specification of the physical noise parameters on which reliance should be placed to protect the majority of workers exposed to noise.

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HEARING CONSERVATION PROGRAMMES IN THE NETHERLANDS INDUSTRY

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INTRODUCTION

Exposure to harmful noise at work places is an extensive problem. In many cases the reduction of noise below a safe level cannot be realized immediately. In those situations a hearing conservation programme has to be carried out to prevent hearing loss due to noise exposure. Using Austrian data,for the Dutch situation an estimation of the number of industrial workers exposed to certain equivalent sound levels was made. The number of factories with equivalent sound levels exceeding 95 dB(A) is estimated to be more than 8 800 (total number of factories 27 000). The total number of industrial workers exposed to equivalent sound levels of 95 dB(A) or more is 88 200 (this is 13 % of the total industrial workers in the Netherlands). About 50 % of all industrial workers is exposed to noise levels of 80 dB(A) or more.

LEGISLATION

Up till now there is no legal standard for noise at work places in the

Netherlands. In 1981 the Minister of Social Affairs asked the SER (Social Economic Council, a tripartite advisory body for the government) to advise on the following policy plans:

- to fix a safe noise limit at work places at an equivalent sound level of 80 dB(A). The employer is obliged to put hearing protection devices at the disposal of the employees who work in equivalent sound levels of 80 dB(A) and more;
- to introduce prohibitive regulations with a possibility for dispensation for factories with equivalent sound levels of 95 dB(A) or more. In these equivalent sound levels the employees are obliged to wear hearing protection devices.

It is also important to note that the Minister of Social Affairs set into force a new act called the "Working Conditions Act". This act demands consultations between employer and employees about the circumstances of the job (safety, health and well-being). Without doubt noise is one of the most frequent occurances and, therefore, shall be one of the topics of these consultations.

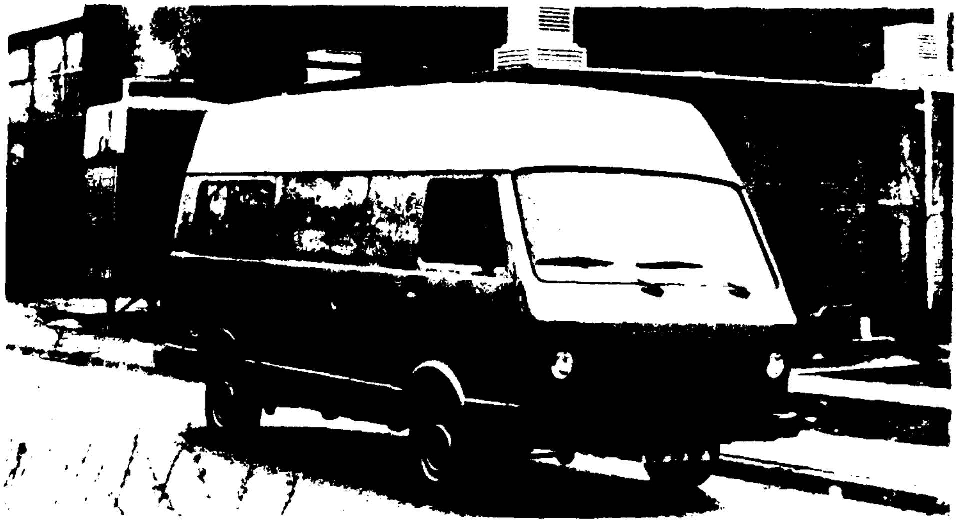
Carrying out hearing conservation programmes in factories and workshops belongs also to the legal tasks of industrial health centres. Under contract with the Ministry of Social Affairs the TNO Research Institute for Environmental Hygiene is carrying out a research project to develop hearing conservation programmes in co-operation with industrial health centres. To that aim a noise team consisting of an acoustician and two industrial audiometricians is carrying out a hearing conservation programme together with the industrial physician. The technical aspects of a hearing conservation programme (audiometry, noise measurements, use of hearing protection devices, registration and analysis of data) are

covered and at the same time a useful schematic structure of information, education and consultation is developed. For these aspects the new Working Conditions Act is a guideline. Such a hearing conservation programme should be usable in all situations where employers are exposed to harmful noise.

ASPECTS OF HEARING CONSERVATION PROGRAMMES

A Hearing Conservation Programme is a programme with activities and measures to prevent noise-induced hearing loss. The work "programme" indicates that it is not a one-day activity, but that the execution of such a programme in a factory may last for years. The aim of the programme is to achieve a situation in a factory such that nobody will have a risk of noise-induced hearing loss. The activities in a Hearing Conservation Programme are:

- Information and education. First, all participants,in the first place directors, managers, chiefs, foremen and other leaders, have to become familiar with the contents of the programme. All persons concerned, from director to employee, have to be informed about practical details, the risks of harmful noise, the use of hearing protection devices.
- Noise measurements and noise abatement programme. An inventory of all jobs in which people are exposed to harmful noise is drawn up. A programme is made to reduce the noise, preferably by quieting the noise sources.
- Audiometry. The hearing of all persons working in harmful noise is tested periodically. To reduce the time needed by the employees a mobile unit is used which is installed as close as possible to the factory. At the same time the employees are questioned thoroughly about possible causes of hearing loss.



- Analysis of data. The data of the audiometric tests and of the noise measurements are stored in computer systems. The anamnestic data and audiograms are stored directly in a small system (HP 85) in the mobile audiometric unit and afterwards analyzed in a large system (HP 1000). The data from the noise measurement are also stored in the systems.

A lot of results thus becomes available, such as:

- individual audiograms
- audiograms of groups of employees, selected by several criteria (equivalent sound level, function, exposure time, age, factory)
- dose-effect relationships
- a system for repeating audiometric tests of individuals, dependent on equivalent sound level, for instance
- results of noise measurements ordered according to type of industry or industrial activity.

TAKING ACCOUNT OF CUMULATIVE ASPECTS IN NOISE ABATEMENT POLICY-SOME PRELIMINARY REMARKS.

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INTRODUCTION

The noise indicators currently in use are,because of their source-specificity,not appropiate for describing the acoustic climat in situations where various noises are responsible for effects on the population.

In this paper two different methods are given for describing the acoustic quality of a given location under the influence of outside noise from more than one source.

THE FIRST APPROACH

The first logic step would be to look for a noise descriptor that takes account of all the caracteristics involved in the annoyance behaviour of humans.Evidence begins to build up that the 10 weighted equivalent sound level does not satisfactorily accounts for the number of events.

The suggestion of Flindell([1]) to take instead the 20 weigthed energy equivalent sound level,which has the effect of greater emphasis on the higher peak levels and the number of events seems worthwile to investigate more thoroughly. The disadvantage as already indicated by Flindell is that there is no convenient way to transform the 10 weighted Leq into the 20 weighted Leq.Even if the the pressure averaged Leq would gain wide acceptance,it would take a long time befor all existing measuring equipment would have been adapted.

In figure 1 a model is proposed for relating peak level,number of events and annoyance.

This model is based on available data from social surveys.Most of them had to be reprocessed using reasonable assumptions for deriving peak levels from equivalent noise levels or other noise indicators.Because of the problems related to inter-survey comparisons a the precise parameters of the model can not as yet be given.

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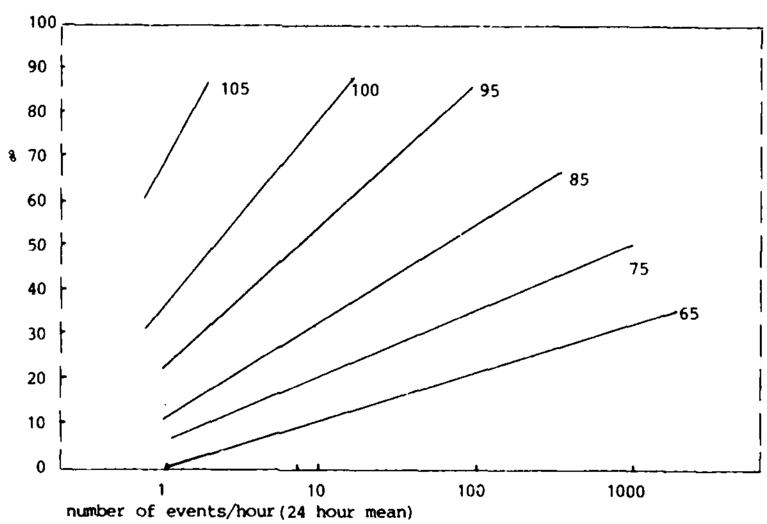

M van den Berg

Figure 1 Percentage serious annoyed against numberof events(log-scale),for peak levels between 65 and 105 dB(A)

Figure 1 suggests (to the suggestable) that untill a peak level of 65 dB(A) annoyance increases in proportion with the 10 lg of the number.At higher peak levels annoyance begins to depend more on the number of events,untill it reaches 25 lgN at the peak level of 90 dB(A) and there are some indications of even higher factors for peak levels around 100 dB(A).

The first hypothesis is now that the energy equivalent sound level should be corrected for the number of events,and that the correctionfactor should depend on the peak level of this event.

For instance,75 dB(A),Leq from a large motorway could than get a correction from 25lg150 =54 (for 150 heavy lorries per hour) whereas 75 dB(A) Leq from a railroad would get a correction of 30lg20=39 ,assuming a rate of 25 for the 85 dB(A) peaklevels from the heavy lorries and a rate of 30 for the 90 dB(A) from the trains.

The second hypothesis , a crucial one for the cumulation situations,is that the correction terms from different sources all can be 'added' to the overall energy equivalent sound level to describe the overall annoyance.

For most noises the number of events and their peaklevels are well known or easy to get by.One should however not underestimate the problem,as in some instances the distribution of peak levels over number of events is far from normal,so a statistical approach is not advisable.

THE SECOND APPROACH.

For purposes like physical planning often the absolute level of annoyance is not that important,but more the question how a certain area relates to another area.Environmental factors are ever becoming more important in deciding if a given location is suitable for housing.As there are a lot of such environmental factors,these decisions are sometimes hard to make.

As long as no 'unifying sound descriptor' can be found something has to be done to describe an area which is exposed to different noises. This can be realized by assuming that the effects of the various noises can be added.

The following procedure then results:

-Two standards are choosen;the lower at approximately the no-effect-level(x_l) , the higher standard at a level from where unacceptable effects are to be expected (x_h).

-The sound levels are then related to the standards,assuming a linear relationship,so a dimensionless index results,for T_x for value x :

$$T_x=\frac{T_g-T_l}{x_g-x_l}(x-x_l)$$

-These indices(one for each noise) are then summed accordingly to the following formula

$$B=\frac{1}{k}\sum_i(T_i)^k$$

where

B= total index

T_i= index for component i

k= exponent,k=lg(9N+1),N is the number of sound levels above x_l.

This method assumes that an area is more unsuitable for habitation if there is more than one noise approaching the unacceptable effect level.

A similar method is currently in use for describing air quality (2) , and is under study for describing the acoustic quality in the Dutch Rijnmond-region.

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A STATISTICAL EVALUATION ABOUT OCCUPATIONAL HEARING LOSS IN IRON-MECHANICHAL WORKMEN OF A VERONESE INDUSTRY.

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INTRODUCTION

In this short work are considered, only from a statistical point of view, the auditory apparatus damages occurring in iron workers of a foundry division, also in relation to noise exposure periods.

MATERIAL AND METHODS

436 men were examined, i.e. each one, at first with "Quick-Check", in the factory, then the suspected deaf persons, put in a silent room, 14 hours after the duty-end.
Working place noise level varied from a minimum of 80-85 dBA (machine-shop, dressing) up to a maximum of 103 dBA (screw-cutting, engraving).

RESULTS

Results in this table are summarized:

NORMAL HEARING

Persons		Percentage
178	"Quick-Check" examination	43%
8	Silent room examination	

NON OCCUPATIONAL AUDITIVE PATHOLOGY

2	Suffering from a serious form of bilateral otosclerosis and from outcomes of a mastoidectomy	0,5%	
8	Uncertain etiology bradyacusia	2%	
30	Transmissive, mixed or perceptive post-otitis bradyacusia	6,5%	20%
48	Mixed bradyacusia with occupational components, joined with presbyacusia, cranial traumas, hunting	11%	

ONLY OCCUPATIONAL AUDITIVE PATHOLOGY

48	Occupational bradyacusia, with bilateral sensorineural hearing loss about 40 dBA at 4000 hz	11%	
90	Occupational bradyacusia with bilateral hearing loss above 40 dBA at 4000 hz and initial sensorineural deafness at 2000 hz	20,5%	37%
24	Occupational bradyacusia with bilateral sensorineural pantonal hearing loss, above 25 dBA from 500 hz frequency onwards	5,5%	

We have now a table and a histogram in which hearing loss percentages in relation to noise exposure periods are considered:

EXPOSURE PERIODS (years)	EXCLUSIVE OCCUPATIONAL HEARING LOSS (%)	NON-OCCUPATIONAL HEARING LOSS (%)	TOTAL HEARING LOSS(%)

5	2,6	0	2,6
6-10	25,5	17,1	42,6
11-15	61,0	14,6	75,6
15	50,0	26,4	76,4

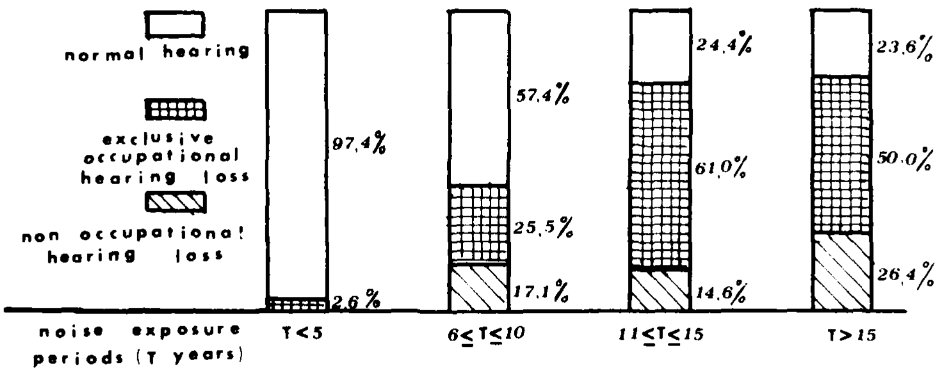

Fig. 1 - Hearing loss in relation to noise exposure periods

COMMENTS AND CONCLUSIONS

Now it should be born in mind that:

n°1) occupational hearing loss does not begin before the sixth year of noise exposition;

n°2) the higest percentage of bradyacusias is to be met with the 11-15 years' noise exposition class; over 15 years later we can see a slightly reduced diminution of occupational bradyacusias, probably in relation to a "selection", in account of which

after 15 years' work the subjects with the highest auditive Handicap are transferred to another division, or pensioned off.

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THE EVALUATION OF DAMAGE IN NOISE-INDUCED HIGH FREQUENCY HEARING LOSS

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INTRODUCTION

Noise-induced, high frequency hearing loss shows, in the early stages, a characteristic dip fo air and bone conduction at 4 KHz. Since 0,5, 1 and 2 KHz are not involved in this process, if we choose one of the methods which attributes no ponderal value to 4 KHz, the degree of invalidity will be inferior to the minimum level needed for remuneration.It follows that, according to Italian law, a subject with professiona deafness showing an exclusive deficit at 4 KHz will not be eligible for remuneration because of the negligible effect that this hearing loss has on his generic working capacity. All the same, such subjects insist that they have difficulty in understanding multiple messages or foreign languages, and that this does have a significant and negative influence on their working capacities during work hours. Presuming that sensitized speech discrimination tests, that reproduce critical hearing conditions, allow one to carry out a quantitative evaluation of damage incurred in reference to a comunication deficit during working conditions, a group of workers with

chronic noise-induced hearing loss at 4-6 KHz underwent accelerated and distorted speech tests. These tests were suggested by Bocca et al. and by others as an aid in the differential diagnosis of central deafness. The application of such tests to subjects with mainly cochlear dysfunction, could seem contradictory. But we believe that sensitized speech audiometry, applied to subjects with no damage to the central pathways, owing to the reduced extrinsic redundancy of the message, should be able to bring to light the presence of deficits resulting from cochlear dysfunction.

MATERIALS AND METHODS

In order to carry out this experiment, we carried out pure-tone and speech audiometry (bisyllabic PB words and accelerated and frequency filtered sentences) on a group of 40 subjects ranging from 20 to 50 years of age, all male, who had asked for remuneration of their hearing loss and its classification as professional deafness.

The subjects were chosen according to the following criteria: no pure-tone hearing loss at 0,5, 1 and 2 KHz; hearing loss was bilateral and approximately symmetrical; negative otoscopic examination; existence of risk conditions for which they could be considered eligible for noise-induced hearing loss.

The phonetical material consisted in:

1. 8 lists of 10 bisyllabic, meaningful PB words (Bocca and Pellegrini);
2. 20 lists of 10 brief, meaningful sentences, which almost all subjects could understand, presented at a speed of 140 words per minute, due to acceleration of tape speed (Bocca and Calearo);
3. 20 lists of 10 sentences similar to those mentioned previously but distorted by use of a low pass, high frequency cut filter with progressive frequency attenuation (Bocca and Calearo);

All the above mentioned material was recorded and produced by Amplifon. The tests were carried out in a silent room with an Audiometer Amplifon 300.

RESULTS

The results brought to light an average age of 30 years, relative to subjects examined and an average threshold of 50 dB at 4 KHz. Average pure-tone hearing loss for 0,5, 1 and 2 KHz was equal to 20 dB HL.

Speech tests with bisyllabic PB words resulted in normal levels of discrimination in all subjects. The sensitized speech tests showed as follows (Figures 1 and 2):

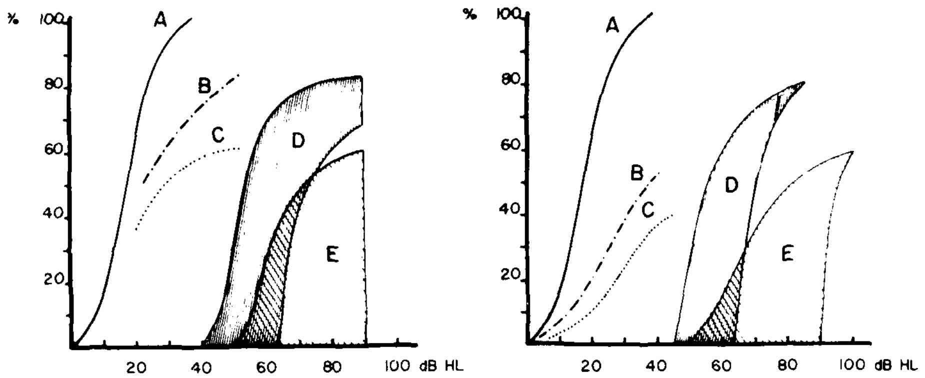

Fig.1 Youths - average age 30 years; Fig.2 Adults - average age 40 years: A - speech articulation curve for bisyllabic PB words; B - standard speech articulation curve for accelerated sentences; C - standard speech articulation curve for frequency filtered sentences; D - articulation field in subjects examined for accelerated sentences; E - articulation field in subjects examined for frequency filtered sentences.

1. Accelerated speech function: a) noticeably inferior to average values (Bocca and Antonelli) showing a SRT shift, with interindividual variability which was greater in older subjects and constant with increased intensity; b) characteristically, most subjects were able to reach maximum intelli-

gibility within an intensity range of 50 - 90 dB HL.

.. Low pass, high frequency cut speech discrimination scores showed deviation from normal values, which were slightly greater in comparison with those relative to accelerated speech. Maximum intelligibility was reached within an intensity range of 40 - 90 dB HL; in 40 year-olds the maximum intelligibility threshold was inferior.

CONCLUSIONS

The comparison between pure-tone and bisyllabic PB speech discrimination functions confirmed the absence of speech-tone dissociation in all subjects; this has already been shown. However there is a noticeable SRT shift exclusively for sensitized phonetic material and this would seem to point to the fact that subjects with a high frequency hearing loss, have considerable difficulty in understanding speech in critical conditions. Therefore once we have eliminated the possibility of interference of the central acoustic pathways, our results would seem to confirm our theory concerning high frequency cochlear damage and its negative effect on speech discrimination in critical listening conditions. Therefore, as far as the medicolegal evaluation of high frequency hearing loss in reference to general working capacity is concerned, we believe that the use of criteria which attribute an almost non existant ponderal value to a deficit at 4 KHz, should be examined more closely, as such criteria are not entirely representative of the general working capacity of eac' single subject.

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STATISTICAL ANALYSIS OF NOISE-INDUCED HEARING LOSS IN INDUSTRIAL WORKERS

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INTRODUCTION

In recent years the number of cases of noise-induced hearing loss reported in italy has noticeably increased. From 1977-1981 the number of cases reported reached 57.303,divided as follows: 11.984 in 1977, 16.333 in 1978; 15.952 in 1979; 13.034 in 1980.

Considering that in the same quadrennium the total number of cases relative to all professional diseases was reported as 198.838, we can assume that noise-induced hearing loss accounts for 27% of all types of disablement.

Noise-induced hearing loss was included in italian insurance policy for the first time in 1952 and the scheme adopted by the employer's liability insurance act (1975)lists 22 different ways in which the damage can be contracted. The lowest level at which professional diseases have a right to compensation has been brought to 11% (decision of the Constitutional Court n° 93,30.5.1977).

MATERIALS AND METHODS

We carried out a statistical analysis of audiometric data relative to 1000 industrial workers who, during the period from 1977-1981, presented and claimed compensation for noise-induced hearing loss. These data were drawn from clinical findings obtained in the course of repeated pure-tone and speech audiometry tests together with specific tests for the detection of malingering, carried out subsequent to strict objective procedures.

In this way, we were able to establish the incidence of hearing loss and the percentage of disablement refered to generic working capacity as a function of age and of the number of years of active service. In order to determine the level of disablement, we used Table IV (Motta et al.).

RESULTS

A. Age distribution of professional disease (Table 1):

Subjects with effective acoustic trauma can be divided into three age groups: 4,6% from 18-29 years of age; 16% from 30-39 years; 79.4% were over 40 years of age.

TAV 1

DISTRIBUZIONE PER ETA'

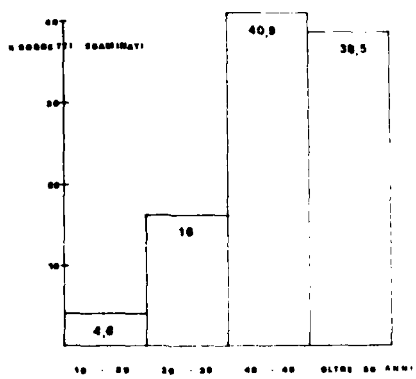
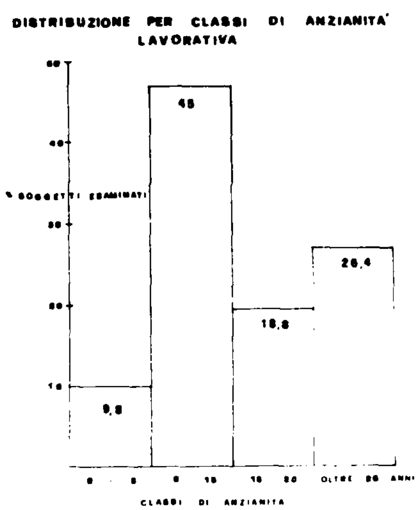


Table 1: Age distribution of professional disease

B. Distribution by years of active service (Table 2):
9.8% of subjects with professional hearing loss belonged to class I (5 years); 45% belonged to class II (6-15 years); whilst the remaining 26.4% had been in service for over 20 years.

C. Distribution of hearing loss (Table 3):
Of the 1000 subjects taken into consideration, 40.9% showed damage inferior to 5%; 19.6% had damage within the 6-10% range; 28.6% within the 11-15% range; and 10.9% above the 16% level.

TAV. 2



TAV 3

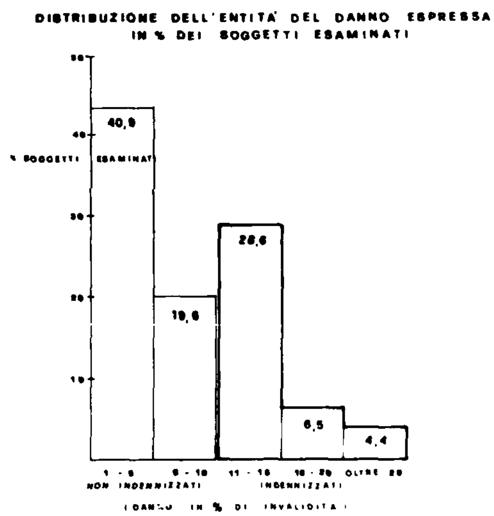


Table 2:Years of active service Table 3:Grade of damage (%)

D. Frequency of damage expressed in permanent disablement percentage values (refered to generic working capacity), as a function of age and years of active service:
The percentage of permanent disablement increases progressively as a function of age and years of active service.

E. Average hearing threshold relative to age and years of active service:

The analysis of average hearing loss at 500,1,2,4 Khz in relation to age and years of active service shows how threshold for 0,5 and 1KHz stays constantly around 20 dBHL despite the above-mentioned factors. At 2KHz there is a significant variability. At 4KHz the threshold drops to 60-70 dBHL as a function of age and to 50-60 dBHL as a function of active service.

CONCLUSIONS

The audiometric data taken into consideration allow us to establish: a) noise-induced hearing loss in the group of workers examined in our study reached maximum frequency for subjects within 40-49 years of age and with 6 - 15 of active service; b) the analysis of audiometric data relative to age and years of active service brings to light how the increase in permanent disability, is directly proportional to the rise of the two parameters (age and years of active service); c) 60.5% of the workers show professional deafness with damage(refered to generic working capacity) inferior to 11%, and thus, by law do not have a right to compensation benefit.

A POSSIBLE ASSESSMENT OF OCCUPATIONAL NOISE EXPOSURE

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INTRODUCTION

Italian law faces problems arising from noise with two articles in the Civil and Penal Code respectively. Owing to the existence of such articles any person who disturbs another by a noisy activity is found guilty, but in each case the Judge has to determine the limit above which the law can operate. In 1956 legislation regulating rights of work considered for the firs time the problem of controlling the consequences of occupational noise: "general rules for hygiene at work" state the rights to intervene where there is shaking, vibration or noise harmful to employees. A law laid down in 1970, better known as "Workers' Statute", states that they have the right to promote, even with the help of outside experts, researching, elaborating and realizing every possible way of preserving their health and their physical integrity. So, neither does legislation regulating workers' rights fix the limit above which the law itself can operate. We must not think that this characteristic, common to every law we have considered here, is a weakness in the law itself: indeed it is a good expedient which makes

the law more adaptable and allows it to keep up to date with the latest techniques for measuring and evaluating noise. A law permitting a boundless action is particularly important in the field of occupational noise control.

THE MEASUREMENT AND EVALUATION OF NOISE

Many researchers have studied the problem of measuring noise correctly in regard to the physiological effects it has on the hearing organs and many papers have been written on this subject. This is not the place to repeat what has already been accomplished about these techniques, nor to expose strong arguments adduced by the Authors to support their thesis. By carefully examining these works we can deduce that all methods proposed have a common shortcoming, which derives from the very nature of the object of "banking" from sound. Human beings are anatomically alike so that some parts can be replaced, but, unlike machines, they have different psycho-physical reactions: moreover the same part sollecited in different individuals in the same way may show an exhaustion resistance which varies depending on a large number of parameters which sometimes escape evaluation. Even if carried out with strict scientific rigour, research on man has to be based on a statistical elaboration of data. Such elaboration, even if extremely correct, can individuate only mean values and dispersion bands. Only in this way we can elaborate a technique for measuring noise as a perturber of the physiological balance of the human body: so we cannot obtain entirely satisfactory results. This fact is well known to researchers, and every Author presenting results on this subject states the limits of validity of his own research: such limits get narrower as the number of individuals on which research has been carried out diminishes, and as a result becomes more refined. This situation becomes more uncertain when we try to put the measure of a noise and the related physiological and pathological effects on the human body side by side. To get out of the blind alley which at this point we risk entering, we must simplify the problem. Examining the papers of the most noteworthy researchers in the field, we notice the common desire to classify every noisy situation with a numeric value accounting for the greatest number of anatomo-physiological characteristics of the human ear. Many Authors conclude their research by suggesting the use of an integrating sound level meter equipped with appropriate weighting networks. Of all these different proposals the most successful, even in an international context, is that based on the well known A weighting network, owing to its simplicity of use and its satisfactory interpretation of the average human ear up to these sound level values which should not normally be superated. We must not disregard the fact that evaluation of effects produced by noise measured in dB A sets the simplicity of execution against the possibility of wrong interpretation: however, if we bear this possibility clearly in mind while utilizing the results of the measurements, we can easily control this hazard.

NOISE AND WORK ENVIRONMENT

We have already seen that the law imposes the adoption of measures to protect workers'health, among which, in particular, are those measures both to reduce environmental noise and to protect workers from damage to hearing by noise. We have also seen that for such a purpose measuring in dB A can produce an efficient technique to evaluate noise exposure and re-

lated damage risk criteria; of course we must bear in mind every [illegible] which derives from evaluating a complex phenomenon - such as noise - with a single numerical value. Every problem exposed in the previous paragraph is emphasized when we try to join sound level values with damage risk criteria in a wide sense. We have a lot of data, deriving from research carried out in particular sectors, with exposure to predetermined noises, with refined techniques which allow us to follow all the phases of the [illegible]tion of the ear in animals used for experiments, but it is only too easy to lose in the midst of all these data. It is a well-known fact that exposure to intense noise also produces non-auditory physiological responses, chiefly on the cardiovascular, digestive and respiratory systems: scarcity of knowledge about these phenomena makes it even more difficult to give advice about the danger of spending many hours a day in a noisy environment. A new element which, owing to the present condition of knowledge, makes the situation more uncertain, has been becoming more and more consistent in the last few years. We may suppose from the undoubted existence of non-auditory effects of noise, that well defined interferences in the opposite direction exist, and not only at a psychological level: that is to say that changes in byological or physiological state of systems, other than hearing, may affect it, altering its faculty to react to sound stimuli. These effects, that we can call crossed effects, escaped the attention of those Authors who carried out their research in environments well fitted for studying noise and so generally troubled only by the desired phenomenon, that is sound. However, studying the effects of noise upon employees operating in industrial environments we can see that the same noise, at the same level, can be variously tolerated depending on the reverberation time of the workshop and, in the same workshop, depending on the presence of other pollutants like smoke, dust, heat and so on. By way of example, I remember a personal experience about a problem of excessive noise and temperature in a metal construction industry. A lot of sound-absorbing material had been fitted, but the results were not technically sufficient to resolve the problem of excessive noise; at the same time the circulation of air had been increased to improve thermal conditions of the environment. Even if noise level abatement is not very good, workers are now less troubled by noise than would be expected. Obviously this is a partial and incomplete experience, which still needs to be studied and which, like other similar cases elsewhere, is made more difficult by environmental problems (we operate in a factory so we cannot introduce modifications and repeat experiences with the necessary speed and regularity, as is possible in laboratory) and from the nature of the experimental objects (we do not work upon anaeshetized animals, but upon men, so we have to operate cautiously, purging psychological effects, at a time unfavourable to research). Anyway I think my observations are correct, as accurate laboratory research has showed that, at least in transient phases, always present during working processes, physiological conditions and particularly body temperature affect normal cochlear response to noise. At this point I think I can confirm what I said in the introduction: it is very difficult to state a satisfactory noise level under which there is no danger, perhaps because this value would have no real basis, so the legislator was right in refusing to indicate it.

CONCLUSIONS

Until now all research carried out to individuate a technique to measure noise, which allow us to evaluate, in the best way possible, if a noi-

se may be dangerous, and if so, to what extent, becomes very useful if we use it to determine an alarm level: in such a line it is useful to carry out further research chiefly towards evaluation techniques of impulsive noises, which are present particularly in many factories and workshops.

Bearing in mind this consideration and also that:

- the same sound level expressed in dB A can be realized with different spectral contents,
- sounds with the same level in dB A and the same spectral content can variously influence the human ear depending on the acoustic environmental conditions,

discussion about quantification of absolute levels which must not be exceeded or about computation technique of noise-dose, becomes meaningless. Rather, it is of great importance to lay down a procedure to medically control workers who are exposed to noise which exceeds a certain guard level: as it assumes the function of alarm, this level must be discovered with criteria of ample security. Such a procedure, even if not clearly stated by the law, can be requested on the basis of the law of 1970 and is already applied, in various ways, at a national level and particularly in many factories in Emilia-Romagna region.

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APPLICATION OF TIME-SERIES ANALYSES TO LEQ-MEASURES OF ENVIRONMENTAL IMPULSE NOISE*

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1 - INTRODUCTION

Procedures based on time-series Auto-Regressive Moving Average (ARMA) modeling are now classical in many domains of signal processing (speech, sismic, EEG, radar signals, etc.). These models have already been applied successfully to non-impulsive sources such as automobile, railway and aircraft noise, making use of short-term Leq-series (integration time between 1 s and 1 mn). Such techniques can be used to analyse complex environmental noise containing impulses. Some preliminary results show that this methodology can be used to detect automatically impulses with single Leq time-series and to extract the impulses with simultaneous Leq time-series.

2 - SINGLE LEQ TIME-SERIES PROCESSING : AUTOMATIC IMPULSE DETECTIONS

When we fit an ARMA model to a time-series, using an adaptative scheme, the variance of the "prediction error" will decrease to a minimum when the time-series is stationary, but increases strongly when the algorithm "reaches" a non-stationarity. These techniques provide a better non-stationary signal detection by observation of the evolution of the prediction error.

Using short-term Leq-series with an integration time related to the duration of the impulses (i.e. far under one second), impulses can be detected automatically in complex environmental noise.

* [illegible]

Example 1 :

It illustrates automatic impulse detection using single Leq time-series (figure 1).

In this case, the total noise included background noise, construction noise and children's shouts (near the microphone).

Construction noise and children's shouts appear as strong non-stationary signals and characterized by a "jump" in the evolution of the variance of the prediction error.

The aircraft flyover, in spite of its high maximum level, is not detected as an impulse, because of the nature of its time pattern.

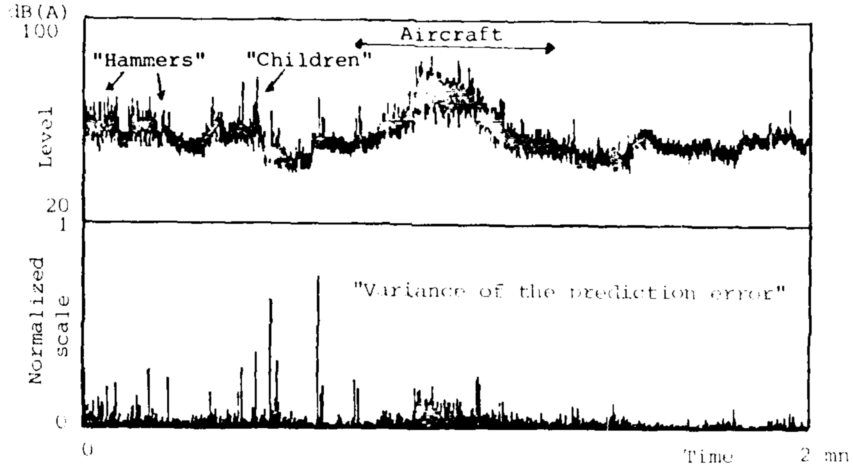

FIGURE 1 : Automatic impulse detection (example 1)

Example 2 :

This is another illustration of impulse detection based on single Leq time-series processing (Figure 2) on a site which is submitted to general background noise and to construction noise.

Again, hammer impacts are very easily detected while a car passing-by is not in spite of its strong signature.

In the above examples, a 4th order Auto-Regressive model has been used. The chosen algorithm is a fast version of the Recursive Least Square (without forgetting factor).

The levels of the "Prediction Error" are related to the level of the non-stationarity (or impulse) and to the degree of non-stationarity of the "Past".

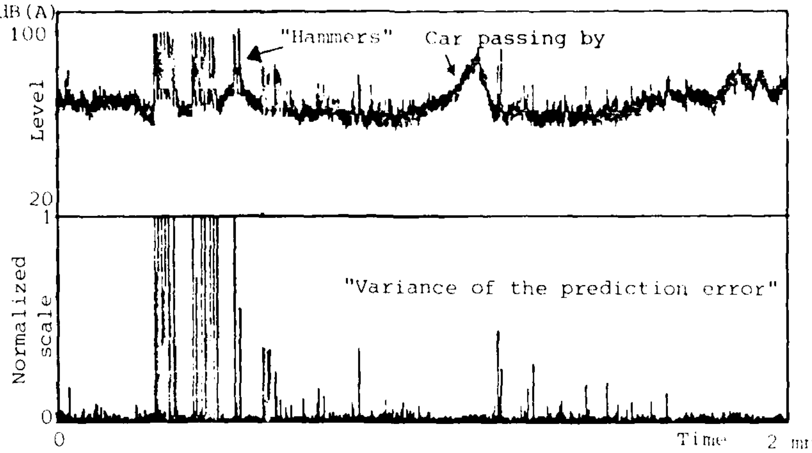

FIGURE 2 : Automatic impulse detection (example 2)

3 - SIMULTANEOUS LEQ TIME-SERIES PROCESSING : ADAPTATIVE NOISE CANCELLING

For the analysis of a complex environment containing multiple sources, it is possible to use a technique called "Adaptative Noise Cancelling" for multiple sources discrimination.

It is then necessary to use simultaneous measurements.

For example, in the case of a *single source of interest*, two measurement points are necessary :

- point 1 is typical of the source of interest
- point 2 is submitted to various noises, among which this source.

At the output of the process, we get an estimate of the Leq time-series at point 2 without the contribution of the *source of interest*, as well as the contribution of this source alone. This process can also be achieved in real time.

Example 3 :

It shows an application of this method to simultaneous recordings taken in a field situation in the presence of impulse noise. The site is the same as that of example 1.

Point 1 is recorded close to the impulse source while point 2 is further away (see figure 3).

It can be seen that after a convergence time, cancellation of the impulse noise at point 2 can be obtained. Since this is due to the correlation of the Leq time-series at points 1 and 2 with respect to the impulse noise, the aircraft noise which also corresponds to a strong correlation is cancelled too. To obtain the contribution of the impulse noise alone, it is necessary to perform an impulse detection after cancelling the aircraft noise.

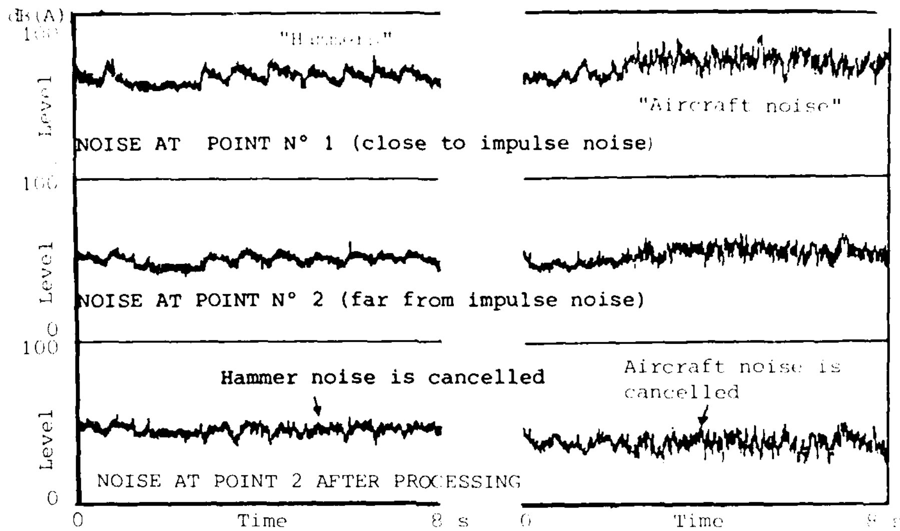

FIGURE 3 : Adaptative Impulse Noise Cancelling (exemple)

4 - CONCLUSION

The application of time-series analysis to short-term Leq's of impulse noise has shown that the detection of impulses is possible even for rather complex signals containing various types of environmental noises. Of course, this discrimination technique is still at its beginning and several refinements are being called for.

Concerning the algorithms themselves, several aspects need to be studied further, such as :

- the effect of the order of the model,
- the use of a weighting time window,
- the problem of synchronizing simultaneous measurements.

Data acquisition also deserves further attention along the following lines :

- *effect of the integration time of the Leq's,*
- *effect of A or other frequency weightings.*

A Common Sense Approach to Workplace Noise Regulation

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Introduction

It is possible to protect each and every worker on an individual basis through implementation of a hearing conservation program like that practiced for many years in the Du Pont Company worldwide.[1] Scientific evidence is presented showing that this goal is achievable without reliance upon compromising percentage risk concepts. Some reasons why this goal of 100% worker protection may not be achieved (nor, targeted) through compliance with present and proposed governmental regulations are examined. New evidence supporting the 5 dBA exchange rate is identified.

Workplace noise regulation has been historically founded on a principle of "acceptable percentage of risk".[2] Reliance upon this principle is unnecessary and unacceptable according to contemporary epidemiological studies.[3,4]

Since a hearing conservation program has been proven to eliminate reliance on the risk principle, it should be considered the primary basis for protection of individual worker hearing health.

Regulatory Proposals

Some regulatory proposals continue reliance upon unproven and impractical equal energy hypotheses and an erroneously derived criterion level of 85 dBA.[1] It seems some regulators would insist that it is necessary to place some workers at risk to draw attention to technical and engineering controls.

We urge those responsible for regulation to adopt a common sense hearing conservation program approach with medical surveillance.

A 90 dBA criterion level with a 5 dBA exchange rate, supported by available scientific evidence, can then be established for technical or engineering controls. We suggest that incentives for these controls be established independent of workplace regulation, preferably at the point of original equipment manufacture (OEM).

Risk Criteria Establish Risk

Direct exposure assessments have not yet been correlated epidemiologically to audiometric test results for test subjects as they have for workplace measurements. For lack of appreciation of the overriding

benefits of a hearing conservation program with medical surveillance and intervention, past studies have been used to establish criteria allowing for (indeed, requiring) some percentage of risk.

Technical or Engineering Controls Establish Risk

Few effective engineering control techniques are available today. This thrusts most engineering control into retrofit, such as enclosures. Completion of technical or engineering controls to a criterion number, ensures that the risk percentage of workers aligned with that selected criterion number, is then placed at risk.

The Hearing Conservation Program Overcomes Limitations of Risk

Dr. Pell concluded from his study[3] that a hearing conservation program whose components include periodic audiometric testing and ear protection, and which utilizes a hearing conservation criterion of approximately 90 dBA, is capable of protecting the hearing health of noise-exposed workers. Dr. Pell's findings are corroborated in a similar study[4] reported in 1974 by Gosztonyi.

The hearing conservation program also provides a basis for monitoring the effectiveness of personal hearing protection.

90 dBA Is the Most Practical Criterion Level

A criterion level of 85 dBA for technical controls is highly impractical, and will remain so for many years to come. Continued misplacement of incentives for technical methods in user oriented workplace regulation will likely delay progress, as more than 12 years of regulation in the U.S. has shown.

The EPA did not properly apply the difference between octave band sound pressure level in dB and sound level in dBA (ie, A-weighted sound pressure level).[5] That error turns present claims for an "85 dB" criterion level to support for 92 dBA or more. A 92 dBA criterion level is in line with Pell's findings.

If any practical, progressive change in present criteria levels is to be made, reducing the upper limit from 115 dBA to 110 dBA would have a positive impact in keeping with hearing conservation goals.

A 5 dBA Exchange Rate (Exposure Level and Time) Is Most Appropriate

We believe that the 5 dB(A) exchange rate, going from the criterion level of 90 dB(A), is the only rational and appropriate choice. Sulkowski,[6] Henderson,[7] and others agree. This is particularly true considering the significant and unnecessary cost penalties associated with going from 5 dB(A) to 3 dB(A) as an exchange rate. A 3 dB(A) exchange rate is based upon implausible zero intermittency in daily worker exposure to noise and a fundamental misconception regarding relationships between addition of decibel levels and equal energy of decibel levels. We also recognize the basic weaknesses of the Burns and Robinson study leading to the "equal energy" hypothesis (EEH).[8]

The actual effects of intermittency were demonstrated in the work of Sataloff, Vassallo, and Menduke with iron ore workers.[9] These investigators found that workers exposed to intermittent noise showed no greater incidence of impaired hearing than workers exposed to steady

noise some 20 dBA lower.

To reject the 5 dB(A) exchange rate in favor of a 3 dB(A) rate requires the assumption that intermittency of exposure and/or sound level has no effect on the manner in which sound levels and exposures relate to hearing loss. There is no basis for such an assumption in the scientific literature and it would seem to go against the universally established natural principle of homeostasis.

The data contained in Beranek's book[2] shows how an appropriate exchange rate depends not only on time and sound level, but also the number of interruptions in the exposure (or level) per day.

The use of the 3 dB(A) exchange rate in a regulation would be valid only for a full shift exposure without any (or perhaps single) interruptions. To assume that workers will have only one interruption, or less in their daily exposure is to ignore the realities of worker exposure in a modern world.

Burns and Robinson assumed individual dose exposures with a variability of 10 dBA or more. In our view this order of magnitude variation virtually eliminates any prospect for those authors, or anyone who considers their hypothesis to discern a distinct preference for a 3 dB(A) rate over a 5 dB(A) rate.

Sulkowski[6] and Borchgrevink[7] have recently produced convincing evidence that the Equal Energy Hypothesis (EEH) is not valid.

We also note that The American Conference of Governmental Industrial Hygienists in its latest (1982) TLV® document clearly specifies a 5 dB(A) exchange rate in Table 8 on page 80.

We agree with Dr. Sulkowski's conclusion, based upon his exhaustive study, (see page 206 of Reference 6),"... it seems that the 5 dBA doubling rate is more appropriate than 3 dBA time/intensity tradeoff value".

Conclusion

The 90 dBA per 8-hour criterion with a 5 dB(A) exchange rate, should be used as the basis for technical or engineering controls in workplace noise regulation. A hearing conservation program should be required first and foremost to protect workers from potential noise-induced hearing impairment on an individual basis, beginning at 85 dBA. A 3 dBA exchange rate based upon an equal energy hypothesis is not valid according to Sulkowski,[6] Scheiblechner[10] and others. Henderson[7] has shown that EEH is not appropriate where there is impulse noise present.

Protecting all workers from potential hearing impairment due to industrial noise exposure is an attainable goal.[11] More than twenty-five years' experience in Du Pont prove it. A hearing conservation program, with medical surveillance, audiometric testing, training and hearing protection where necessary and appropriate, is a tested and practical procedure. Present and proposed noise regulations, establishing preference for technical methods or engineering controls to some risk related criterion level, cannot produce such protection for as many individual workers in industry. Practical technical methods or engineering controls necessary to meet a 90 dBA criterion level are not generally available[12] and 85 dBA would further emphasize their impracticality.

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ULTRA-AUDIOMETRIC STUDY OF 'NORMAL' NOISE-EXPOSED LISTENERS

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INTRODUCTION

High-frequency audiometry is a relatively new field in the study of noise-induced hearing loss. Many authors have studied the high frequency function in relation to an existing noise-induced sensorineural hearing loss with its classical dip centred at 4-6 KHz. Sataloff et al.(1967) carried out a survey on paper mill workers, testing frequencies from 250 to 14000 Hz, using a group of subjects who weren't exposed to noise as a control group. This study, in which the subjects were divided into groups by decades, brought to light the existence of a significant variance between the two groups for each single frequency.

Lutz (198[illegible]) claims that after one year of noise exposure workers present a selective loss at 16-18 KHz. Dieroff (198[illegible]) in a study carried out on [illegible]00 weaving industry workers ranging from [illegible]0-40 years of age, who were exposed to noise and presented a dip at 4-6 KHz, found a threshold deficit above 15 KHz, which was more marked in those subjects who were continuously exposed to noise.

In contrast to the data presented by these authors,

Robertson and Williams (1975) in a survey carried out on a sample of training pilots after their first flying session, who showed no evidence of threshold dip with traditional audiometric procedures, referred no deviation from the norm for high frequency levels.

Osterhammel (1980) studied 28 subjects, ranging from 30-59 years of age and divided into groups by decades and reached the conclusion that high frequency audiometry cannot be used as an early index of noise-induced hearing loss: in fact, according to this author, even in presence of damage at 4-8 KHz the average high frequency audiometric function is still within normal limits.

On the basis of these studies we decided to examine the high frequency function in a group of young noise-exposed subjects with normal audiometric findings, in the attempt to bring to light an early,selective involvement of hearing within this specific range. In other words we tried to assess whether high frequency audiometry can be considered a predictive method for the pre-clinical identification of noise-induced hearing loss.

MATERIALS AND METHODS

We selected subjects ranging from 20-29 years of age who showed no evidence of any general or specific pathology that could influence the hearing function.

These subjects belonged to a group of joiners and carpenters who worked as scene builders in the television studios. All had 1-3 years of active service and had been exposed to noise stimuli under homogeneous temporal and intensity conditions (95 dB Eq).

These subjects underwent pure-tone and impedance audiometry after a 48 hour rest period. we further selected 24 subjects from this group who showed normal findings for the above mentioned test procedures, in order to carry out high frequency audiometry.

The testing was carried out with an Oscillator B&K 1014,

a home-made attenuator with 5 dB steps, a high-pass filter with cut)off frequency at 6 KHz. As suggested by Fausti et al. (1979) the transducer was a Koss headphone HV/1A, able to give a flat response up to 20 KHz at an intensity superior to 100 dB SPL. The stimuli which had a duration of 1 second, were triggered by a home-made electronic switch with rise/fall times of 100 msec. The tests were carried out in a silent room.

RESULTS

Figure 1 compares the average high frequency function for these subjects, with that relative to the control group, made up of 50 normal subjects belonging to the same age group who underwent identitical test procedures. The comparison of average values, the standard deviation and, above all, the statystical analysis of the significance of the data, brought to light the abscence of statistical significance in the data concerning these two groups.

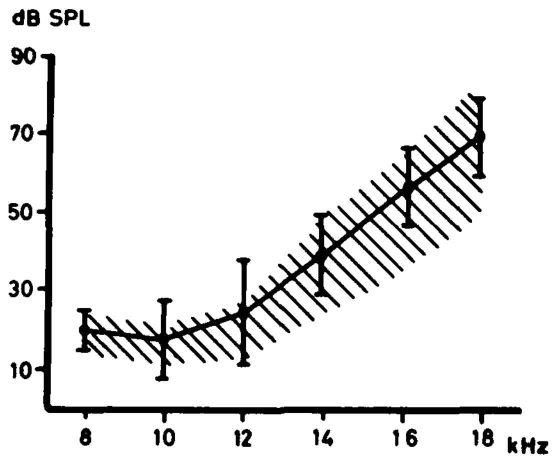

Fig.1 Mean and standard deviation values for high frequency function in noise-exposed subjects.(Shaded area = normals).

CONCLUSIONS

The data extracted from our survey enables us to claim that there was no early involvement of high frequency hearing in the noise-exposed group taken into consideration. This find-

ing does not contrast with those referred by Osterhammel who denies the existence of any correlation between the dip at 4-6 KHz and a high frequency hearing loss. As far as the studies carried out by Sataloff and Dieroff are concerned, even though they are based on different suppositions, we can see that our results, which apparently seem to contrast with the findings of these other authors, do not actually contradict them. In fact, it is possible that a dip at 4 kHz can exist parallel to a high frequency loss.

Such data would seem to indicate that high frequency audiometry, even though it cannot be considered a predictive measure of noise-induced hearing loss, can however be used as a valid integrative procedure able to complete the test battery relative to this important problem.

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HEARING DAMAGE CAUSED BY IMPULSE NOISE - RESULTS OF A SWISS INVESTIGATION

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INTRODUCTION

There is no generally accepted damage risk criterion for impulse noise. Various rating methods are proposed, including the equivalent A-weighted sound energy (LEQ, LAX/SEL), fixed or variable correction factors to be added to the Leq [ISO, DIN/VDI, Brüel] and level/duration criteria for unweighted signals [Pfander, CHABA].
To evaluate the different methods, a mobile 32-channel real-time measuring system was developed [1], which was used for over 300 field measurements of industrial impulse noise and weapons impulses.
Original PTS (permanent threshold shift) and noise exposure data from more than 250'000 people as well as over 600 cases of hearing damage caused by weapons were available to search for relations between acoustic parameters and noise-induced hearing loss.

MEASUREMENT OF IMPULSE NOISE

Acoustical noise measurements must take into account the characteristics of the human ear. Figure 1 shows the transfer function from the free sound field to the cochlea, based on data from MEHRGARDT [2] and STIRNEMANN [3], and the curves A, D and the combination of A and D ("A*D"). The flattening of the equal loudness contours at higher levels must be due to the nonlinear coding process of the hair cells. Therefore at least

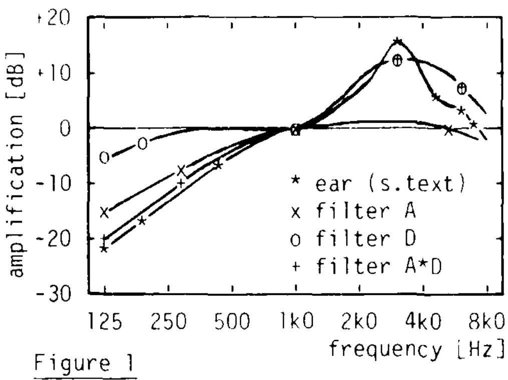

Figure 1

the filter A should be used for impulse noise, but a better simulation of the outer ear resonance is highly desirable.

The frequency analysis mostly applied to impulse noise is the FFT, although the transient behaviour of the basilar membrane is similar to octave or third-octave filters.

1/3 octave analysis and weighting according to figure 1 showed that at the input of the inner ear, nearly 90 % of the noise sources produce a spectral peak between 2 and 5 kHz. The audiometric dip at 4-6 kHz must therefore be explained by the transfer function of the human ear and a level-dependent shift of damage location to higher frequencies [4].

In the time domain, one possible reason for an excessive damage risk of impulses is the delay of the acoustic reflex. The DIN/VDI method based on this assumption introduces a penalty of up to 17 dB for isolated impulses by integrating the impulse-weighted DC-output of a SLM ("impulse correction").

Some authors suppose short peaks to be extremely dangerous. As a compensation, Brüel proposed to add the difference $L(A)_{Peak} - L(A)_{Impulse}$ to the LEQ ("peak correction").

LONG-TERM EFFECTS OF IMPULSE NOISE

Since 1971 SUVA has been collecting PTS and noise exposure data of over 250 000 persons. Initial evaluations of these data displayed considerable differences to the predictions presented in ISO draft 1999 (1981), specially for low noise exposure. To avoid problems caused by differing age-related hearing loss or sociacusis, the mean hearing loss (CPT-AMA) of a group exposed to a specific noise situation was compared to the mean hearing loss of a reference group with identical distribution regarding sex, age, noise level and exposure time.

Then the noise level correction necessary on account of the actual hearing loss was calculated. So noise level corrections are positive, where the average hearing loss exceeds the one predicted on account of the Leq. If impulse noise were more hazardous than continuous noise of equal A-weighted energy, then this level correction should correspond with the impulse correction and/or peak correction.

Results:

- The level correction calculated for the metal industry does not surpass the level corrrection for the wood industry.
- No correlation was found between the level correction on basis of hearing loss and the peak correction proposed by Brüel. Perhaps the peak correction was applicable for measurements with earlier SLMs set at "slow" response.
- On the average, only 1/3 of the impulse correction according to DIN/VDI is justified. For isolated impulses an increase in level of up to 5 dB is adequate.

HEARING DAMAGE CAUSED BY WEAPONS

For 180 cases of hearing loss caused by weapons impulses without previous noise exposure the A-weighted sound energy based on the acoustical measurements, the number of impulses and the acoustic environment was calculated. On the other hand, the binaural hearing loss (CPT-AMA), from which the average hearing loss of a reference group without noise exposure was subtracted, allowed to correlate the sound energy of the damaging event and the mean hearing loss (figure 2). The regression line shown intersects the base line ("no NIHL") at about 125 dB SEL (=LAX).

The average PTS caused by a single blast of 125 dB SEL is comparable to the PTS after 10 years exposure to 92 dB(A) for the same age group. This result indicates, that a SEL of 125 dB exceeds the limit of mechanical damage to the inner ear ("critical level"). The fact that the new Swiss army standard rifle (SR2, SEL ≥128 dB) led to a significant increase in hearing damage, supports this criterion.

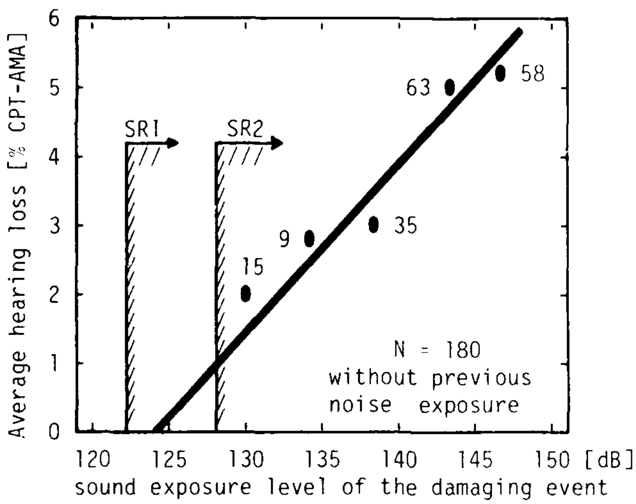

Figure 2

Hearing damage caused by weapons impulses: sound exposure level (SEL) of the damaging event and the resulting average hearing loss [% CPT-AMA]

CONCLUSIONS

For hearing conservation, industrial impulse noise is preferably assessed by the LEQ measured with accurate *integrating* SLMs. The impulse correction after DIN/VDI overrates the risk presented by impulses.

The daily sound energy allowed by a limit of 90 dB(A) LEQ must however not be concentrated into an extremely short time, because above 125 dB(A) SEL mechanical damage to the inner ear may occur.

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ACKNOWLEDGEMENT

This work was supported by the Swiss National Accident Insurance Fund SUVA.

HEARING LOSS DUE TO IMPACT NOISE IN THE DROP-FORGING INDUSTRY

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INTRODUCTION

Two independent studies of noise and hearing loss in drop-forging industries have been conducted in Europe. The National Institute for Occupational Safety and Health obtained original data from these studies for the development of a data base on impact noise. Results of these studies have been reported by Sulkowski et al. (1978; 1980) and Taylor et al. (1983) previously. The noise exposure conditions included in these two studies allow for comparison of different techniques which have been used to determine equivalent continuous noise levels for impact noise, and, comparison of noise exposures with approximately the same overall noise levels, but with different impact noise and background noise components. In all cases, the impacts occur at a rate of less than one per second, the point at which impact noise has been commonly distinguished from continuous noise. The purpose of this paper is to compare hearing loss in two populations exposed to approximately equivalent noise in different locations.

The Sulkowski data for analysis included 790 hammer forge workers from three different factories in Poland and 169 control subjects with no history of occupational noise exposure. Subjects with ear pathology or previous noise exposure and forge workers with less than one year at the forge are not included. Noise data for 163, 208, and 419 workers at Factories I, II, and III shown below were used by Sulkowski et al. to calculate equivalent continuous A-weighted noise levels using the technique of Atherly and Martin (1971).

Factory	Peak Level (dB)	Decay Time (sec.)	No. of Impacts per Day	On Time (hrs.)	Average Rate per Second	Impact Level, L_I(A)	Back-ground L_B(A)	Overall Level L_{eq}(A)
I	126.4	0.03	20000	6.0	0.69	101	109	110
II	135.0	0.09	9700	3.5	0.34	111	107	112
III	133.4	0.06	16000	-	0.57	110	88	110

As reported by Sulkowski (1980), comparison of hearing data from Factory I

(L_{eq}=110 dB) with that from Factory II (L_{eq}=112 dB) indicate no significant differences between the two groups. In each of these two cases the background noise levels are within 5 dB of the overall L_{eq} values. For Factory III (L_{eq}=110 dB) however, the background noise level is 22 dB below the L_{eq} value. Comparison of median hearing levels from Factory III with those from Factory I-II shows substantially less hearing loss from Factory III.

The Taylor (1983) data for analysis included 505 hammer forge operators, 211 press forge operators, and 293 office workers employed in forges in the United Kingdom. Subjects with ear pathology or significant noise exposure not associated with their occupation and forge workers with less than one year of exposure are not included. Equivalent continuous A-weighted noise exposure levels for hammer and press forge operators were determined using data from personal noise dosimetry. Dosimeters were worn by forge workers over the course of 8-hour workdays. The hammer operators had an average L_{eq} of 108 dB and the press operators had an average of L_{eq} of 99 dB (A-weighted values). Background noise levels were less than 90 dB.

Previous comparisons of Taylor's impact noise-exposed subject hearing data have been made with hearing loss data due to continuous noise presented by Robinson (1970) and Passchier-Vermeer (1968). These comparisons indicated reasonably close agreement between hearing loss statistics for subjects greater than 35 years of age with 10 or more years of exposure.

DISCUSSION

Comparison of the two control populations shown in Figure 1 indicate very little difference between median hearing levels at 500, 1000, and 2000 Hz. At 3000, 4000, and 6000 Hz, progressively higher median hearing levels appea in the Sulkowski population. This may be explained by the fact that Sulkowski's control subjects are all male, whereas Taylor's controls are primarily female and the differences shown are typical (Passchier-Vermeer, 1968). The close agreement between hearing levels for the 15-24 age groups indicate a high degree of compatibility between the two studies.

Hearing data from Factories I-II combined (L_{eq}=111 dB) in the Sulkowski study and those for hammer operators (L_{eq}=108 dB) from the Taylor study are shown in Figure 2. The median hearing levels are similar and indicate agreement between the two studies and between these studies and data from Robinson at an exposure level of about 108 dB. However, in this case the Sulkowski data show more hearing loss for age groups with average exposure times of less than 10 years and less loss for exposure times of greater than 10 years when compared to the Taylor data. Previous comparison of Taylcr's impact noise to models of continuous noise indicated less hearing loss due to impact noise for exposure times of less than 10 years. The indication of more hearing loss for exposure times of less than 10 years in the Sulkowski data in this case may be due to the relatively high background noise level of 108 dB, i.e., the more continuous nature of the noise exposure.

Similarly, comparison of hearing data from Fac ry III (L_{eq}=110 dB) in the Sulkowski study with those for press operat s (L_{eq}=99 dB) in the

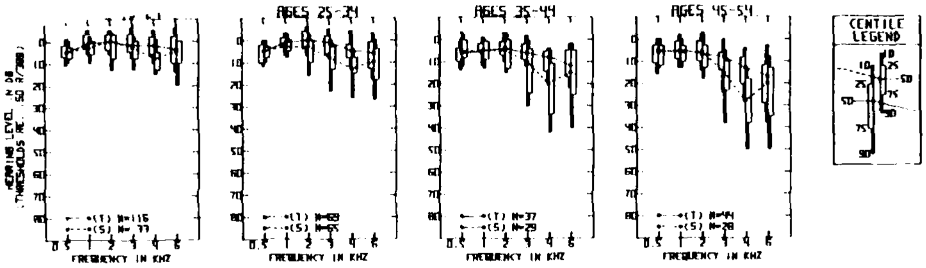

Fig. 1 - Percentile hearing level distributions of control subjects in Taylor (T) study compared with control subjects in Sulkowski (S) study. (Solid lines connect median (50%) hearing levels for (T) study; dashed lines connect median levels for (S) study).

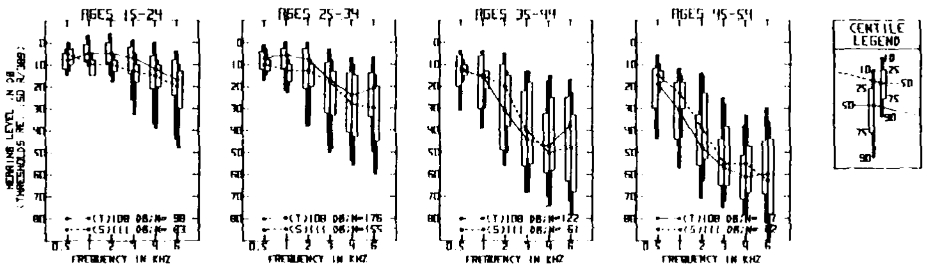

Fig. 2 - Percentile hearing level distribution of hammer operators in Taylor (T) study compared with workers from Factories I-II in Sulkowski (S) study. (Solid lines connect median (50%) hearing levels for (T) study; dashed lines connect median levels for (S) study).

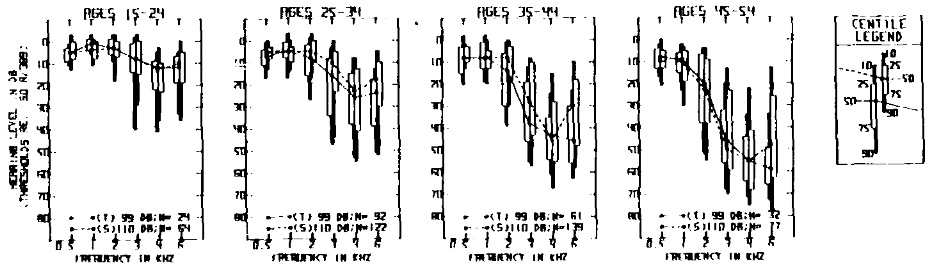

Fig. 3 - Percentile hearing level distributions of press operators in Taylor (T) study compared with workers from Factory III in Sulkowski (S) study. (Solid lines connect median (50%) hearing levels for (T) study dashed lines connect median levels for (S) study).

Taylor study (see Figure 3) indicates the hearing l... Factory III (L_{eq}=110 dB) are no greater than those for press operators (L_{eq}=99 dB). This result and comparison of Factory III with Factories I-II suggest the possibility that the L_{eq} of 110 dB for Factory III determined by the method of Atherly and Martin using "typical" values of the impact noise parameters may not be an accurate assessment of the equivalent continuous noise level that would have been determined had the noise been "integrated" over all values of these parameters typical to an 8-hour workday.

Further evidence of the need to assess possible measurement error is ...dicated by the fact that Atherly's and Martin's evaluation and ...lculations of impact noise levels in the same plants that Taylor conducted his study indicated levels of 118 dB and 110 dB for hammer and press operators as compared to values of 108 dB and 99 dB found in the Taylor study using dosimetry. Assuming values of L_I (computed using Atherly and Martin's method) are 10 dB high, Sulkowski's Factory III would have an L_{eq} of 100 dB and Factories I-II combined would have an L_{eq} of 108 dB (i.e., L_{eq}=L_B). Thus, the results would indicate that the populations in the two studies consistently exhibit the same hearing loss for the same equivalent continuous exposure.

CONCLUSION

The original data obtained from the two sources appear to contain unexplained errors in the measurement of the stimulus. In order to accurately evaluate exposure to high impact noise levels, techniques used for the measurement require further investigation. The weakness of the studies lies in this area, as shown by the differences in L_{eq} values and secondly, there is the difficult question of the influence of the continuous background noise on the overall hearing loss. If further resolution can be made of the presence of error in either or both of the two measurement techniques, controversy concerning whether hearing loss can be accurately assessed using equivalent continuous noise levels for impact noise exposures could be more clearly understood.

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TEMPORARY THRESHOLD SHIFT AFTER EXPOSURE TO NOISE AND MUSIC OF EQUAL ENERGY

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INTRODUCTION

Our previous investigations revealed that pop musicians showed less temporary threshold shift (TTS) than experimental subject-listeners after pop concerts, in spite of the fact that musicians were exposed to higher sound levels (Axelsson & Lindgren, 1978). The findings suggests that other factors influence the individual development of TTS than the physical properties of sound (exposure level, exposure time, and frequency distribution). Indeed, this focuses on a possible influence by noise on extra-auditory functions and the psychological experience of sound (Chüden & Strauss, 1973,1974; Hörmann et al., 1970; Ismail et al.,1973; Jansen, 1970; Schönfeld, 1979).

The aim of the present study was to determine individual differences in TTS after repeated controlled exposure to noninformative noise and to music, with equal time-, frequency- and sound-level characteristics.

MATERIAL AND METHOD

The experimental subjects were ten voluntary teen-agers (nine males and one female) with a mean age of 16.2 years (range = 16 - 17 years) and with normal pure-tone thresholds. Middle ear pressures and contra-lateral

acoustic reflex thresholds were within normal range.

In order to obtain two "identical" exposures with different information content, a selection from a musical performance was used as a basis. The music was a recorded 5 min continuous part of a pop-concert, duplicated to result in a 10 min exposure. The frequency distribution, sound pressure level (SPL) distribution and SPL-variations for the musical exposure were carefully monitored. A non-informative exposure was then created by feeding the music through an octave filter and into a level analyzer in order to obtain an electrical signal with the same characteristics in each octave band. The electrical signal then controlled an attenuator which was fed with an octave-filtered noise. This procedure was repeated for each octave band from 63 to 8000 Hz. These noise-bands were gathered and comprised the 10 min noise exposure. The L_{eq} per 10 min in each octave band as well as SPL-variations and maximum and minimum SPLs in each octave band were comparable to the music exposure. Measurements showed that overall SPLs as well as the dB(A) level were equal for the "noise" and music. Each subject was in randomized order for 10 min exposed on five occasions to noise and on five occasions to the music at L_{eq} 106 dB(A).

TTS was determined from pre- and post-exposure pure-tone thresholds established with computerized sweep-frequency audiometer (type Békésy) in the frequency range 1000 - 8000 Hz. The test tone was delivered to the subject over an insert earphone in order to minimize variations caused by misplaced earphones. The post-exposure threshold determination started 2 minutes after cessation of the exposure at 1000 Hz (TTS_2).

RESULTS

Individual analyses of TTS-data demonstrated a marked discrepancy in mean TTSs between the two stimuli for six subjects while four subjects showed only slight differences. However, in all cases where differences were obtained, this was due to more TTS after exposure to noise. Typical mean TTSs after five repeated exposures to each stimulus are shown for two subjects in Fig. 1.

In order to establish possible significant variations in TTS between the two stimuli, the difference in TTS at each noise session and at each music session was calculated for each individual, at each test frequency and at each paired session (i. e., first noise TTS subtracted by first music TTS, second noise TTS subtracted by second music TTS etc.,). Mean paired differences were significantly shifted at 2000, 3000 and 4000 Hz ($p < 0.01$) and at 5000 Hz ($p < 0.05$)(Fig. 2).

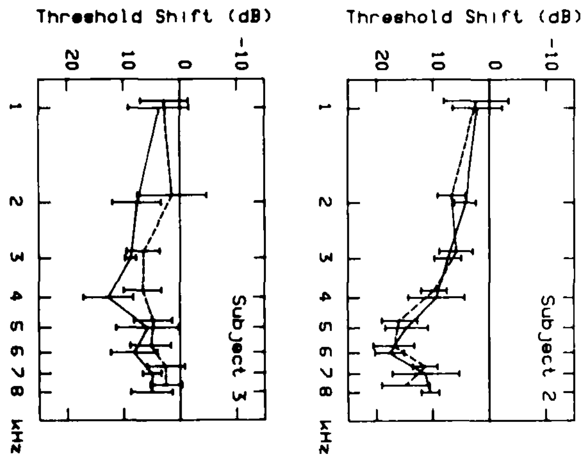

Fig. 1 - Mean TTS for 3 individual subjects after five exposures to noise (unbroken line) and five exposures to music (broken line). Standard deviation is indicated by vertical bars.

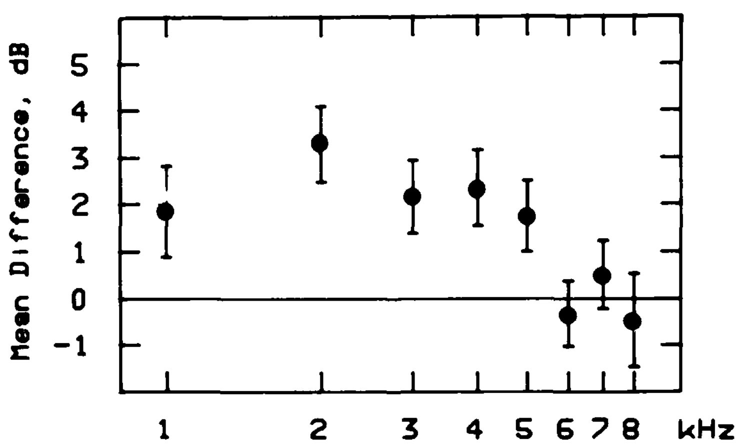

Fig. 2 - Mean of five paired session differences for noise/music $\pm$ 1 S.E.M. (vertical bars). N = 50.

CONCLUSION

The results do indicate a difference in TTS-susceptibility caused by psychological factors and it seems possible that in this limited population there were differences in TTS caused by factors such as the subjective experience of the noise versus the music. It might be speculated that if a noise that produces more TTS than another one is also more hazardous in longstanding exposures it could ultimately result in a more pronounced permanent noise induced hearing loss. High sound-levels that are experienced as unbearable, unpleasant and unnecessary would then induce more hearing loss than sound at excessive levels, but with positive emotional content.

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ACKNOWLEDGEMENTS

This work was supported by grant 81-0236 from the Swedish Work Environment Fund.

REDUCING INDIVIDUAL SUSCEPTIBILITY TO NOISE DAMAGE -- HISTORICAL REVIEW AND PROPOSAL FOR INTERNATIONAL COLLABORATIVE RESEARCH

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INTRODUCTION

For nearly a decade, we have been investigating the effects of Carbogen (95% O_2, 5% CO_2) inhalation on noise-induced hearing impairment. Our findings have indicated the following:

1. Carbogen inhalation prior to, during, or immediately after noise exposure reduces TTS and hastens recovery from TTS (Joglekar, et al. 1977, Brown, 1980);

2. Carbogen inhalation has been found to reduce histologically observed cochlear sensory cell damage in experimental animals exposed to dangerously great sound levels (Witter et al., 1980); and

3. Carbon dioxide is the apparent active ingredient that increases resistance to noise-induced effects (harris and Lipscomb, 1981).

These results have led to a search for an effective means of providing controlled CO_2 inhalation for industrial workers. It is obvious that large tanks and breathing masks are infeasible. Therefore, we turned to the rebreather, a device into which persons breathe and

receive approximately 5% CO_2 for the period the rebreather is used.

MATERIAL AND METHODS

There remains a need to investigate several parameters to determine whether use of a rebreathing device is effective in increasing individual resistance to high level noise exposure. At present, we are limiting the scope of such investigation to those persons whose noise exposure is:

1. marginal (80 to 90 dBA daily noise dose);
2. due to inadequate ability to provide hearing protection (work environment in excess of approximately 120 dBA);
3. persons who arrive at work with TTS from noisy transportation vehicles; or
4. persons who engage in high noise level non-occupational activities and who arrive at work with a TTS.

In the case of subject classes #1 and #2, the intent of rebreather use will be to increase resistance to noise-induced hearing impairment. For those in subject divisions #3 and #4, use of the rebreather upon arriving at work is thought to enhance recovery from the previous TTS as well as assist in decreasing susceptibility to noise-induced hearing impairment.

Apparatus is simple. The rebreather to be used is a one-liter capacity unit that is completely collabsable such that it can be placed into the worker's pocket or other small compartment. A nose clip is integral with the rebreather to seal off the nasal passages assuring the breath stream is directed entirely into the rebreathing unit. The rebreather is disposable and inexpensive, so a new unit can be provided to worker subjects each day.

Design considerations for a multiple-location study include some fundamental elements:

1. Workers will use the rebreather for three minutes immediately upon entering the workplace;
2. At the morning break, at the beginning of the lunch break, at the end of the lunch break, at the afternoon break and immediately at the end of the shift, the rebreather will be used for three minutes.
3. Hearing testing of each worker subject will take place at the beginning and end of the work day for three successive days during which rebreathers are used.
4. For three successive days, each participant will receive pre- and post shift hearing tests and will be seated alongside subjects using rebreathers for three minutes, but will not use the rebreather (sham condition).

A history will be taken that will include questions regarding non-occupational noise exposure, noise exposure history, subject description of their hearing and subject reaction to the rebreather.

RESULTS

It is anticipated that such an international cooperative study

will provide close scruiteny of a promising new approach to hearing conservation -- physiologically based hearing protection. Rather than simply blocking the pathway of sound, the proposed approach utilizes established physiological responses to provide limited hearing protection. Its success and future utilization can only be determined if numerous applications are investigated using typical industrial worker subject classifications.

CONCLUSION

It is proposed that representatives of industry in different nations engage in a cooperative study with our coordinative efforts. Using the basic research design described above and utilizing rebreathers we will provide for workers, we hope to collect and analyze valuable data concerning the efficacy of rebreathers as physiological hearing protective devices for use in industrial settings for employees marginally exposed to noise or for whom hearing protection is inadequate.

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THE CURE FOR NOISE-INDUCED HEARING LOSS IS PREVENTION

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There is a dearth of basic information on noise-induced hearing loss. A national magazine's cover story with an interview format, "How Modern Life Can Damage Your Hearing," omitted to ask the most important question, 'Is there any way that a person can protect his hearing from noise?' We read about sound levels at the cinema. "Led Zeppelin pulverizes eardrums! Even using squashed-up balls of paper napkin, it was loud!"

In 1972, Dr. Donald Belt, audiologist of the Stanford Medical Center, testified before the Committee on Public Works of the U.S. Senate. He proposed that legislation be enacted to establish a public education program, using the various media to provide information on noise and hearing loss, in order to help citizens to conserve their hearing. This important program was never established.

In 1979, at a seminar in San Francisco, Lt. Col. Donald Gasaway, USAF, emphasized that noise-induced hearing loss is totally preventable, but that an individual may have to lose hearing before becoming interested in protecting it. Col. Gasaway noted that no information is given

in Health lectures and that there is an urgent need for public education. Protection of the 4000 Hz. receptors is critical. Speaker after speaker stressed education for all, in order to change the attitude of the public toward noise as a hazard.

In 1981, Dr. Aram Glorig, in an editorial, said that school systems are failing to emphasize the importance of hearing and its conservation, especially the hearing of children. He recommended that parent-teacher organizations, school physicians and nurses, develop regular and continuing programs about the importance of hearing and the danger of noise exposure, whether it be loud music or any other type of loud noise.

My own research attempts to discover school programs produced little data. I quote from the few responses received.

An educator in Seattle, WA. tells me; "As far as hearing loss in schools is concerned, there doesn't appear to be any particular interest in a significant program of this kind. I have visited a number of shop classes and none of the students nor the instructors were wearing any hearing protection."

From Peobody, MA., a Coordinator of Reading said; "I am very concerned about the hearing problems we are encountering here in the school. There is little concern on the part of administrators or the local hospital. We do nothing on 'Hearing' in any curriculum." (A group of students had developed hearing loss within the same frequency range.)

From Eudora, Kansas, a teacher wrote the U.S. Environmental Protection Agency. "There was an assembly presentation of one of our Air Force bands. When they started playing, the volume was excruciating. We, as an institution, should not be contributing to this abuse of our young persons' ears."

A Director of Hearing Education Services commented in an article; "The number of hard-of-hearing children is not likely to decline significantly in the future; the advent of loud noise damage is likely to escalate."

The title of an article in the "Hearing Aid Journal" sums it up; "Why Not Amplification In Every Classroom?"

I call for every individual at this International Congress to involve himself, or herself, in an ongoing public education program, in his or her home community.

Such a program would provide answers to questions on every aspect of noise, hearing, hearing loss and hearing protection. The three warning signals of early damage, given to its owner by the ear itself, must be described and emphasized. These are: (from "Guide to the Conservation of Hearing in Noise" of the American Academy of Otolaryngology.)

1. Difficulty communicating by speech when in the noise,
2. Head noises or ringing in ones' ears after noise exposure,
3. Temporary hearing loss when voices sound muffled after several hours of exposure to noise.

Finally, the program must teach the consequences of noise exposure; exactly what it is like to be hard-of-hearing; to have lost 'workable hearing for speech,' essential for happiness. Frances Warfield expresses it best in her autobiography, "Keep Listening." "Impaired hearing can invade the dignity, undermine the personality, and damage the living spirit. It can strike at the human being's basic needs; love, self-acceptance, financial and social adequacy." This need not happen! We all must make sure that it will NOT happen!

ADDENDA for ACTION

Environmental noise, which does not harm hearing, acts by disturbing the individual emotionally. The remedy, for unavoidable and annoying noise, is to block it from the ears with earplugs.

Promote legislation to establish safe sound levels for stereo headsets and for amplification in indoor and outdoor public places.

Urge manufacturers of hearing protection to enter the consumer market; to contact all health professionals with literature and samples, as do drug companies; and to advertise in equipment manufacturers' catalogs.

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ACKNOWLEDGEMENTS

I wish to thank Aram Glorig, M.D., Los Angeles, Ca., E. I. Cleveland, M.D., Bronxville, N.Y., Donald Belt, Ph.D., Sunnyvale, Ca., and Jeff Morrill, Ph.D., Kansas City, Mo.

TINNITUS AND OCCUPATIONAL EXPOSURE TO NOISE

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INTRODUCTION

It is generally agreed that acute and chronic acoustic trauma can predispose towards tinnitus (Hempstock, 1971) as a result of lesions to the hair cells of the Corti's organ. However, there is still a considerable lack of knowledge about the prevalence of the phenomenon both in the general population (Hinchcliffe, 1961) and in populations occupationally exposed to noise (Coles, 1981), and about the extent and severity of the disturbance it causes. The aim of this study was to answer some of these questions by investigating the possible relationships between noise, age, hearing threshold and tinnitus.

MATERIAL AND METHODS

The study covered 577 male workers aged between 20 and 59 yaers (mean 38.3 y., standard deviation 7.8 y.), employed in tramcar body repair shops. Noise in the working environment was measured with a BeK Model 2209 Precision Sound Level Meter and a BeK Model 4428 Dose Meter. The L_{A8} (A-weighted equivalent continuous sound level in decibels normalized to 8 hours) was calculated for each task. For each worker was calculated an index representing the percentage of accumulated noise dose, compared to a selected reference value (85 dB x 10 years = 100%). Tinnitus was investigated in all cases with a questionnaire filled in by the same interviewer. The questionnaire contained items about tinnitus presence, duration, intensity, frequency of occurrence, annoyance caused, date of onset, date of last episode, whether or not medical help had been sought. Tinnitus was classified as slight, moderate or severe. Workers reporting

tinnitus without specification of its characteristics were considered not affected.
The interviewer collected also data on consumption of alcohol, smoking habits, previous occupational exposure to noise and non-occupational causes of hearing loss.
After ear drum examination, the hearing threshold was measured with a 150 -calibrated Amplifon audiometer in a sound-isolated test room.
The following programmes were used for automatic data analysis in the description stage:cross-tabulation programme, programme for calculation of elementary descriptive statistics (mean and standard deviation), and the programme for constructing frequency distributions. All these are from the SPSS package. For analysis of the multiple contingency table the GLIM programme was used to estimate the parameters of the logistic model that was considered suitable to describe the relationship between tinnitus, hearing threshold, age, previous and current exposure to noise. The programmes are implemented on a UNIVAC 1100/80 computer at the "Consorzio Interuniversitario Lombardo per la Elaborazione Automatica"(CILEA).

RESULTS

The 577 workers, whose length of service in the present job ranged from 0.5 to 36 years (mean 8.3 y., standard deviation 6.3 y.), were exposed to the following noise levels: 33.4% to ($\leq$ 80) dBA_{Leq}, 31.0% to (81-85) dBA_{Leq}, 15.9% to (86-90) dBA_{Leq} and 19.7% to ($\geq$91) dBA_{Leq}. Tinnitus was considered absent in 71.6% of the workers, slight in 9.1%, moderate in 11.2% and severe in 8.0%.
Medical help was sought by 27.0% of the cases of slight tinnitus by 37.0% of moderate and by 62.5% of severe.
No relationship there was between alcohol and tinnitus, smoking habits and tinnitus ($p > .25$).
Prevalence of tinnitus increases with age ($p < .05$ test for χ^2 trend). However, taking into account the reported date of onset of tinnitus, the maximum of "incidence" was in the 40-44 years age class. This result is only suggestive, given the limits dependent on the cross-sectional nature of the study. 41.6% of the subjects were normally hearing (NH), 33.5% have a noise-induced hearing loss (NIHL) and 24.8% have hearing loss due to other causes (OCHL).
Fig.1 show the means hearing loss at different frequencies and its standard error for subjects without tinnitus, with slight, moderate and severe tinnitus. The subjects were divided into

24 subgroups using: age$\leq$35 y. or $>$35; previous exposure yes or not; noise dose$\leq$35 or $>$35; hearing threshold, NH, NIHL, OCHL. The percentage of subjects with tinnitus ranged from 8.5% in the subgroup with the lowest level to 32.0% in the sub group with the highest level of factors considered. Tinnitus resulted at 5% significantly associated with exposure and hearing loss due to either noise or other causes and not significantly with age and noise dose.

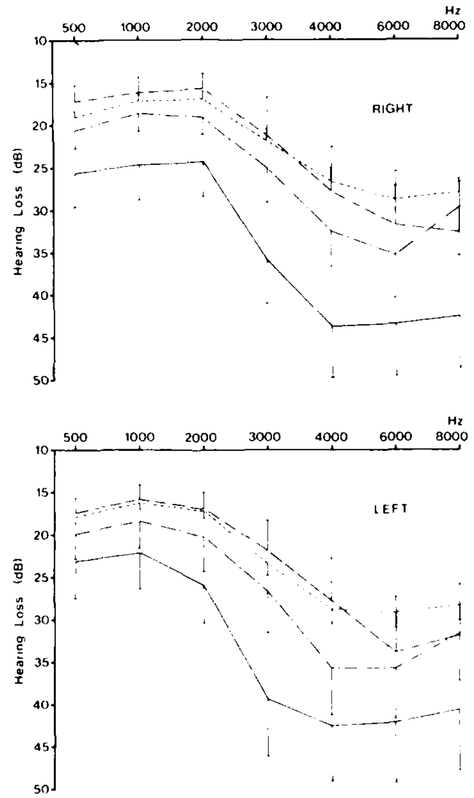

Fig. 1 - Right and left hearing threshold, mean and standard error (2 x ES). Subjects without tinnitus (······n.413) with slight (– – – – n.37), moderate (–·–·–·–n.54), severe tinnitus (—— n.40).
33 cases with last episode of tinnitus before 1981 missing.

CONCLUSIONS

28.4% of the subjects reported tinnitus. This causes moderate or severe annoyance in 19.2%. Of the 4 variables considered,age, previous exposure to noise, current exposure to noise, hearing threshold, the most strongly associated with tinnitus was the hearing threshold. Of the 164 subjects with tinnitus, 29.8% were N.H., 43.9% were N.I.H.L. and 26.2% were O.C.H.L.; of the 413 subjects without tinnitus the percentages were, respectively, 45.8%, 30.7%, 23.5%. In the subjects with NH, 18.3% had severe tinnitus, while in those with HL the percentage was 31.2%. Thus in the subjects with NH, the cases of tinnitus were fewer and less severe. There was no significant difference between the group exposed to a noise dose$\leq$ 35 and $\geq$35. On the other hand, past exposure to noise was associated with a significant increase in the number of cases of tinnitus, while the age seems not to be associated with it. The maximum "incidence" of tinnitus, estimated in our data, occurs in the 40-44 years age class. The data collected allow us to conclude that probably the factors capable of causing hearing damage also predispose towards tinnitus. Since noise is responsible for a large number of cases of hearing loss, it should be considered the most relevant one.

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TOPODIAGNOSTIC PHYSIOGNOMY OF NOISE INDUCED HEARING LOSSES

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INTRODUCTION

Noise-induced hearing loss has been the object of many research for the study of the most varied anatomo-physiological and clinical aspects. However, relatively little attention has been paid to the problem regarding the behavioural pattern of pure-tone topodiagnostic tests. This study takes this aspect into consideration, using the most recent and reliable audiological test procedures.

MATERIAL AND METHODS

Subjects: we selected 77 subjects with noise-induced hearing losses, ranging from 25 to 64 years of age; all subjects had from 12 to 30 years active service. They were subdivided into three different groups: 32 railway engine drivers, 29 metal industry workers and 16 cement industry workers. For all subjects the length of noise exposure was a constant factor, equivalent to 8 hours per day a weekly rest period of 48 hrs. The subjects had no otological impairment and the basic hearing test brought to light a typical dip almost always centered at 4 KHz.

Test procedures: for each single subject we studied the behaviour of tests for cochlear functions by means of the measurement both of the recruitment (test of Metz, SISI test and SISI saturation test) and the elasticity of the cochlear partition (Remote Masking); for retrocochlear involvement

(Carhart Tone Decay test, STAT test and the Anderson reflex decay test); and for central auditory impairment (tonal MLD). The tests were carried out as described by the single Authors (Metz, 1946; Carhart, 1957; Jerger et al., 1959; Anderson et al., 1969; Quaranta et al., 1978, 1979; Cervellera et al., 1980). The SISI test, the Carhart Tone Decay test and the test of Metz were all carried out at 4 KHz; whilst the Reflex decay test and the STAT procedure were both carried out at 1 KHz.

RESULTS

Engine drivers (32 subjects): the SISI test was positive (>70%) bilaterally in 13 cases and unilaterally in 4; the Carhart test was never found to be pathological (>30 dB), but it was uncertain (15-25 dB) in 8 subjects. Metallurgists (29 subjects): 9 of these workers, gave normal results; 15 had a gap reduction (<60 dB) in the test of Metz - bilateral in 11 and unilateral in 4; the contralateral reflexes were absent in both ears in 1 subject and in only one ear in 3 subjects; as far as decay is concerned, Anderson's decay test was pathological in 3 case. Therefore, 2 subjects gave contraddictory results because both the presence of recruitment and the abnormal decay. Cement industry workers (16 cases): the SISI saturation level was found to be <50 dB in 8 of these workers, which would seem to indicate the presence of recruitment, whereas in 5 other subjects it was unascertainable; Jerger's STAT test revealed pathological decay in only 4 subjects, one of whom also presented a pathologically reduced SISI saturation level. Other tests: in 13 (65%) of the 20 subjects taken into consideration Remote Masking values were inferior to the norm, but only in 2 of these were ≤10 dB which, in our experience, is indicative of cochlear rigidity typical of severe hydrops in Ménière's disease; the MLD test, carried out exclusively in 22 cases, showed values <7 dB - inferior limit of the norm for our equipment - in 7 cases

(32%), but only 1 of which had a definitely pathological level ($\leqslant$5 dB).

Table - Audiological findings in 77 subjects with noise - induced hearing losses: pathological results.

Subjects	N.	Recruitment tests	Remote Masking	Decay tests	MLD
Engine Drivers	32	17	carried out in 20 subjects	0	carried out in 22 subjects
Metallurgists	29	15		3	
Cement Workers	16	8		4	
TOTAL	77	40	2	7	1
%	100	52	10	9	5

CONCLUSIONS

The topodiagnostic physiognomy of noise-induced hearing losses (table) is characterized by the presence of recruitment in 52% of the cases and by the unusual finding (9%) of tone decay. The fore-mentioned factor was a more direct expression of noise damage and we found it was linked more to the degree of the deficit, more than to age and years of active service. The abnormal decay was an infrequent finding limited to few individuals and did not seem to depend on excessive exposure to noise. As far as the extrasensorial structures of the inner ear are concerned, the results of Remote Masking test seem to suggest that the harmful action of noise exposure does not affect the elastic properties of the vibratory elements, carriers of the acoustic wave. Finally, our studies show that the noise functional damage is limited to the 1st neurone, since the MLD's value was almost constantly normal.

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DETERMINATION OF NOISE AND ITS EFFECTS ON HEARING IN A METALWORKING FACTORY

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This paper reports a study on noise in a metalworking factory, and an epidemiological assessment of the effects of exposure to predominantly impulse noise in workers subjected to harmful sound stimuli. The factory in question produces support trestles for electricity distribution lines from steel plates and profiles of carying thickness up to 13 metres long. The following operations: metal grit blasting; stamping of marks with pneumatic hammers; tracing and punching; shearing and cutting; punch-drilling; fly press or hammer bending, are carried out in two large workshops (about 80,000 m^2). There is thus a prevalent, ubiquitous danger of high noisiness, mainly of an impulse and repetitive impulse kind. In a few areas, the noise may be defined as continuous, though its intensity and spectrum vary.

MATERIALS AND METHODS

Noise measurement; a Bruel-Kjaer Model 2209 precision phonometer was employed with a ½" condenser microphone. The impulse time constant was used for impulse noises, and the slow constant for continuous noise. Measurements were taken under various operating conditions. The effective impulse value (RMS) was recorded. The peak signal value was measured in

the case of particularly high impulse levels only to make sure that it did not exceed 140 dBA.

Subjects: all 324 male workers were examined. They were 19-59 yrs old (mean 38.3) and had been working in the factory for 1-39 yr (mean 18).

Assessment of effects on hearing: otological histories for each subject were combined with tonal audiometry (air and bone conduction) on 0.25, 0.50, 1, 2, 3, 4 and 6 kHz, and direct otoscopy. The examination was epidemiological rather than clinical or medicolegal, so that the procedures and interpretation criteria were of the screening type.

Examinations were conducted in an isolated, but not totally silent room some distance from the workshop. Audiometry was performed during working hours. It was preceded by acoustic repose of at least 60', since it is felt that the TTS is mostly cancelled during this period (Glorig, 1958). For the purposes of the present study, the data were used solely to ensure positive differentiation of noise-induced hearing loss from that due to other causes and normal tracings. The eight classes proposed by Klockhoff et al. (1972) were employed for the results of screening audiometry.

RESULTS

- NOISE MEASUREMENTS. Table 1 summarises these as the range of sound levels measures at the centre of areas where machines were operating in the usual way, and as the range of maximum sound levels observed near the noisiest work stations. Sound levels varied from one area to another, but were always very high. They formed the typical background of a workshop handling average and large steel profiles.

(initial and advanced TAC); those with a defect also covering to a varying degree the medium and low frequencies (appreciable and advanced slight noise hearing noise); those with normal audiograms or hearing losses of another type

It can be seen that only 28.1% were free from hearing defects as-

cribable to exposure to noise, and that as many as 34.8% (113 persons) were suffering from hearing loss. No significant difference was observed between impulse and continuous noise as a cause of hearing defects. To obtain a correct evaluation of the influence of the duration of exposure

TIPO DI RUMORE	LAVORAZIONE	LIVELLI SONORI PREVALENTI	VALORI MASSIMI DEGLI IMPULSI
IMPULSIVO (dBAI)	Punzonatura	11[illegible]-119	118-128
	Stampigliatura pneumatica	1[illegible]-11[illegible]	12[illegible]-122
	Piegatura con bilanciere	95-100	118-119
	Cesoiatura	110-11[illegible]	120-122
IMPULSIVO RIPETITIVO (dBAI)	Bulinatura	115-118	119-122
CONTINUO DI INTENSITA' E SPETTRO VARIABILI (dBA slow)	Taglio di angolari	123-12[illegible]	124-130
	Molatura	98-102	102-104
	Sabbiatura	91-92	
CONTINUO DI FONDO (dBA slow)	Motori, sistemi di estrazione dell'aria	97-96	

EFFECTS ON HEARING: The audiometric tracings (Table 2) are show in function of the type of ambient noise. Subjects are divided into three categories: those with a perceptive defect confined to a deep on 4 kHz

	LAVORAZIONE	Numero Addetti	DEFICIT DA RUMORE				NON DEFICIT DA RUMORE	
			TAC		IPOACUSIE		NORMALI E ALTRE IPOACUSIE	
			n°	%	n°	%	n°	%
RUMORE IMPULSIVO (95-119 dBA)	Punzonatura	142	46	32,3	49	34,5	47	33,1
	Stampigliatura	45	17	37,7	20	44,4	8	17,7
	Piegatura	28	11	39,3	11	39,3	6	21,4
	Cesoiatura	24	12	50	6	25	6	25
RUMORE IMPULSIVO RIPETITIVO (115-118 dBAI)	Bulinatura	17	10	58,8	4	23,5	3	17,6
RUMORE CONTINUO (91-126 dBA)	Taglio	33	13	39,3	14	42,4	6	18,3
	Molatura	13	4	30,7	2	15,4	7	53,8
	Sabbiatura	22	7	31,8	7	31,8	8	36,3
	TOTALI	324	120	37,08	113	34,87	91	28,1

to such intense noise, 142 workers exposed to this noise only were divided into 3 classes based on length of exposure to eliminate the influence of previous periods of exposure (Table 3).

n° anni di esposizione	normali n°	normali %	TAC n°	TAC %	IP[illegible] n°	IP[illegible] %	TOTALE
1 - 10	7	38,9	8	44,4	3	16,6	18
11 - 20	8	7,7	53	51,4	42	40,8	103
21 - 30	1	4,7	8	38,1	12	57,1	21
TOTALI	16	11,2	69	48,6	57	40,1	142

Tabella n° 3 : Distribuzione dei deficit uditivi in un gruppo esposto a rumore solo in questa fabbrica in funzione degli anni di esposizione. Tasso di prevalenza localizzato.

The local prevalence rate was calculated to provide data that could be compared irrespective of the number in each class. There was a prevalence of 38.9% of persons with normal hearing among those exposed for periods of up to 10 years. This figure gradually decreased, and 57.1% of those exposed for 20 years presented a noise-induced hearing loss.

DISCUSSION AND CONCLUSIONS

The audiometric tracings showed a very high frequency of noise-induced hearing defects (71.9%, with hearing loss in 34.8%). It could be objected that the results are too high because the examination was not carried out in a silent room, and only 60' after leaving the workplace, owing to a threshold shift. Account was taken of this point by calibrating the audiometric tracings to meet the examination conditions. From the interpretative standpoint, wide diagnostic categories were whosen to avoid mathematical evaluation of the audiometric profile, since this would not have been appropriate to the principles and methods of epidemiological investigation. It was also found that more than 90% of

those exposed to the noise of this factory alone displayed a hearing defect after 11 years of exposure, and that 57.1% presented a hearing loss after 20 years.

In conclusion, this study underscores the seriousnes of the risks associated with noise even in factories were such noise is primarily impulsive.

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SAMPLING METHODS AND MEASUREMENT OF IMPULSE NOISE

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INTRODUCTION

The Field Study reported here formed part of a Commission of European Communities project to investigate the effects of impulse sounds on human beings. The study was carried out in parallel with a laboratory study which investigated the annoyance of impulse sound in the laboratory. The overall objective of the project was to compare the annoyance of impulse and non- impulse sounds at the same level, expressed in LAeq, and to determine whether any adjustment to the impulse sound is necessary in order to equate it to the non- impulse sound. The study was therefor designed to determine:

1. the annoyance caused in the community by certain specified impulse sounds in the presence of different levels of road traffic noise;

2. a technique to be used to obtain noise data that would adequately describe the noise environment within specified area.

The Field Study Group comprised two teams: a social survey team and a noise measurement team. The work of the noise measurement team only is described here; that of the social survey team is presented by de Jong et al. at this conference.

STRATEGY

The noise measurement programme was carried out in four specific stages:

1. identification of areas containing sufficient dwellings for valid social surveys to be conducted;

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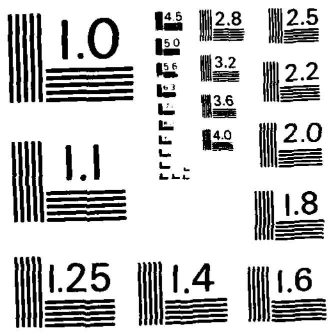

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2. segregation of dwellings within the areas into separate noise zones;

3. specification of procedures to obtain data to be used to describe the noise environment;

4. detailed characterisation of noise environment within zones.

Because of the particular difficulties encountered in obtaining data from impulse sources which produce sounds of extremely short duration, which are often intermittent, which may be audible for only short periods of a day and which may not occurr daily, special measurement techniques were developed. These techniques are described in this paper.

SOURCES

Different sources were investigated: pile driving, scrapyards, drop-hammers, shunting yards, shooting ranges (civil and military), and ship-building yards. The study was carried out using the same methods in 4 European countries: France, Ireland, The Netherlands, and West Germany.

MEASUREMENTS

The measurements took place in two stages:

1. Selection of zones within an area surrounding an impulse noise source with at least a difference of 5 dB between zones.
   Criterion: LAFmax of a representative series of impulses (fast response reproduces the shapes of the pulses best). A minimum of three zones must be available within any area.

2. Characterisation of zones.
   Criterion: LAeq,24h of the total noise load for 3 days.
   First day with a read out of LAeq each minute.

   Equipment: B&K 4426, slow response, 10 Hz sampling rate. Slow response reproduces true LAeq best.

To reduce measuring time, a long- term measurement was made only in the loudest zone. In all other zones, concurrent tape recordings of 15

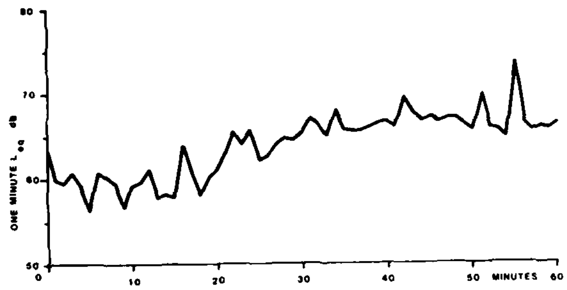

FIG. 1

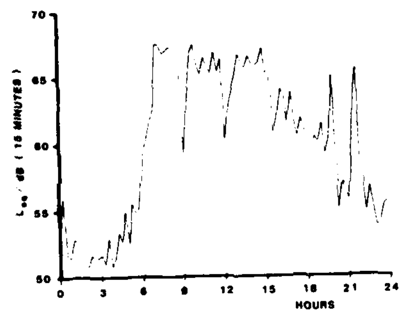

FIG. 2

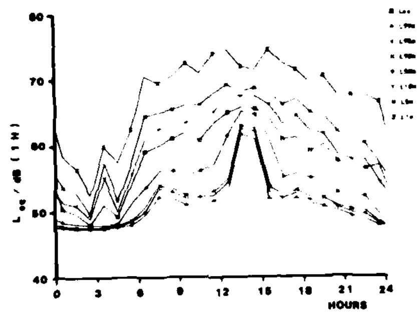

FIG. 3

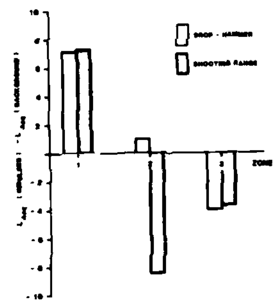

FIG.4

FIG. 5

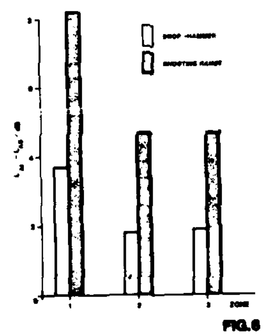

FIG.6

min. duration were taken. It was hoped to evaluate a representative LAeq from these recordings.

ANALYSIS

Data analysis was performed as follows:

time history of LAeq (1 min.) over 24 h (see fig.1)
time history of LAeq (15 min.) over 24 h (see fig. 2)
time history of LAeq (1 h) over 2 days with some hourly percentiles (see fig.3)

Tape analysis: LAeq (15 min.), slow response, separate analysis of LAeq (impulses) and LAeq (background). The identification and the switching were subjective (i.e. under control of the operator carrying out the analysis).

To characterize the impulsiveness, "emergence" was defined as:

LAeq (impulses) - LAeq (background)	(subjective)	(see fig. 4)
LA1% - LA95% over 15 min.	(statistical)	(see fig. 5)

Further LAI - LAS was derived. (see fig. 6)

At a high repetition rate the first method cannot be used. A median single event level, LAx, for single impulses was also measured. When high emergence (10 dB or more) out of the LAeq (15 min.) occurred, a representative LAeq (24 h) was derived from the tape recordings. In other cases an estimation was made of LAeq (24 h). If the impulses were irregular, a monitoring period of 15 min., or even 3 days, for the long-term measurements, may be too short. In future studies, different measurement methods should be considered.

USE OF SNOW-MOBILES AND HEARING LOSS AMONG REINDEER HERDERS.

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INTRODUCTION

There are few reports suggesting a noxious effect of snow-mobile noise on hearing (Bess and Poynor 1974, Baxter & Røjskjaer 1979). In the present paper the effect of snow-mobiles, which have been used for less than 20 years in the northern parts of Finland, was examined among people who otherwise have had rather limited noise exposure.

MATERIAL AND METHODS

Three of the authors (M.S., P.S. and H.K.) accompanied by an audiometrician made a journey through Lapland during which altogether 338 reindeer herders, 331 men and 7 women with a mean age of 41.2 years (S.D. 12.0; range 16-79), were examined. The otologic history was taken and an otolaryngological clinical examination was performed. The audiometry was done by means of a Madsen TBN 85 audiometer in a sound-treated cabin which was built into a caravan van. Both AC and BC thresholds were measured. The subjects had not been exposed to noise during the day of the examination.

RESULTS

Audiometry results of 334 subjects are available for analysis. Of them, 54 right (16.2 %) and 55 left (16.5 %) exhibited a hearing loss of class IV in the Finnish classification for occupational hearing screening. Briefly, class IV means a PTA worse than 20 dB and quite a marked high tone loss. The mean thresholds of the whole material are shown in fig. 1.

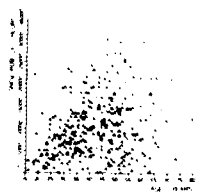

Fig. 1 - Mean AC thresholds of 334 reindeers herders, thresholds exceeding maximum output of *audiometer excluded.*

The snow-mobile seemed to be the most prominent exposer followed by shooting. The amount of snow-mobile use rised up to the age of 50 years of age (fig. 2). The older men had also some other occupational noise exposure as well as noise exposure during World War II in their history.

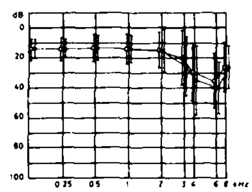

Fig. 2 - Use of snow-mobile versus age among 334 reinder herders.

Table 1 - Noise exnosure among 334 reindeer herders.

	Mean	S.D.
Snow-mobile	10 109.6 (hours)	6 469.1
Motor-driven saw	1 550.6 (hours)	2 508.5
Outboard motor	1 771.3 (hours)	1 005.3
Rifle	1 441.0 (rounds)	2 747.5
Shotgun	2 281.7 (rounds)	1 690.8
Pistol	1 063.7 (rounds)	1 660.3

When subjects over 50 years of age, having used a motor-driven saw over 1000 hours, having used an *outboard motor over 1000 hours*, having shot over 1000 rounds and/or having suffered from ear diseases were excluded, only 56 subjects were left. Even in this small material the highest correlations with hearing loss were found for age and snow-mobile use.

Only 109 (32.8 %) of the subjects used hearing protectors regularly when driving the snowmobile while 181 (54.2 %) never used them. When the

hearing losses were analyzed in a purified material (see above) the use of motor-driven saw being over 1000 hours, however, an almost significant difference ($p < 0.05$) was found between the regular users and the non-users in the left ear (fig. 3). Most of the users were 22-32 years of age.

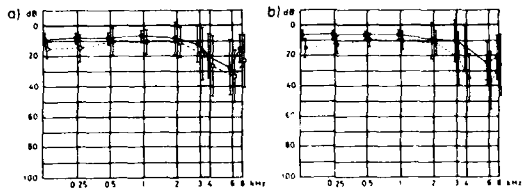

Fig 3 - Mean Ac thresholds and use of hearing protectors among 41 reindeer herders; solid line = regular users, broken line = non-users; a) right ear, b) left ear.

CONCLUSIONS

The amount of hearing losses in this material was quite remarkable and also the mean thresholds were worse than expected (Draft International Standard ISO/DIS 7029). The figures of ISO may be irrelevant for this population living - until lately - in an almost silent environment. Unfortunately mean hearing thresholds for Lappish people do not exist.

The noise exposure levels caused by snow-mobiles used in work have been measured to exceed 100 dB(A) (Anttonen 1982). In our material, the correlations between the use of these vehicles and hearing loss were quite clear. Such a correlation has been suggested also in earlier reports both for hunters (Baxter and Røjskjaer 1979) and racers (Bess and Poynor 1974). The probability of snow-mobile as the cause of a hearing loss is confirmed by the fact that by efficient hearing protection during driving the grade of hearing loss was significantly diminished in the left ear.

A more pronounced hearing loss in the left ear, on one hand, and a more favourable effect of hearing protection in that ear, on the othee, are quite interesting. Lately, a more pronounced susceptibility to noise

in the left ear has been proposed (Chung et al. 1983). Furthermore, in a material of healthy young adults the left ear has been shown to be worse than the right one (Riihikangas et al 1982).

The use of hearing protectors was alarmingly scanty. The better use among younger men was obviously due to more positive attitudes. Very often, however, the use of cup-type protectors was complained to be impossible because of danger of freezing of the face in the cold and windy conditions of Lapland. The in-the-ear protectors, on the other hand, are rather imprcatical to be used with hands soiled by oil which seems to be a rule when using a snow-mobile.

In conclusion, quite a few cases of hearing loss obviously caused by snow-mobiles, were found in the material consisting of Lappish reindeer herders. The left ear seemed to be more affected and also more susceptible to noise trauma when unprotected.

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THE TOTAL-ENERGY AND EQUAL-ENERGY PRINCIPLES IN THE CHINCHILLA.

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INTRODUCTION

The simplest expression of a "total-energy" theory would be that the mean auditory damage $\bar{D}_i$ measured in some specified manner, caused in originally-normal ears by exposure to acoustic stimuli, is some monotonic function of the amount of energy E that has entered the ear over the lifetime of the individual, or

$$\bar{D}_i = f(E).$$

No one seriously espouses this proposal, because it is clear that the spectrum of the noise exposure is a relevant factor. Therefore the most general energy principle that has received any support is the "total-A-weighted-energy" theory (TAWET) in which A-weighted is is applied to the energy reaching the ear, or

$$\bar{D}_i = f(E_A) = f\int_0^T p_A^2(t)dt$$

The main a priori objection to the TAWET is that the temporal pattern of the noise exposure is presumed to be unimportant. It is known that the auditory fatigue produced by a given exposure energy is reduced when the exposure is intermittent; reasonable grounds for believing that a similar phenomenon may not occur in the development of permanent damage have never been advanced. One can therefore reasonably expect that if the TAWET has any validity at all, it would apply best to one particular temporal pattern--or perhaps one should say lack of temporal pattern--specifically, to single continuous (uninterrupted) exposures.

Only Kraak (1982) seems to seriously support a TAWET, and then only for impulse noises of high intensity and short duration; although all his empirical formulas do ignore temporal pattern, he believes that the evidence for ordinary moderate noises supports the total-A-weighted-pressure theory (TAWPT), viz.

$$\bar{D}_i = f\int_0^T p_A(t)dt$$

Somewhat less pretentious than the TAWET or TAWPT, the equal-A-weighted-energy theory (EAWET) does not ignore temporal pattern completely. Instead, it postulates that for a particular temporal pattern of noise and quiet the damage will be a function only of the energy in the noise exposures. The temporal pattern of most practical interest is of

course the workweek of 8 h/d, Monday through Friday, and so what has often been carelessly called "the" *equal-energy theory* is actually the *equal-A-weighted-daily-energy theory* (EAWDET). Although, as a rule, those who promote the EAWDET fail to state precisely the assumptions embodied in their theory, the most widely touted principle, as evidenced by its adoption by ISO (ISO/1999), postulates that the temporal pattern within the workday is irrelevant, so that

$$\bar{D}_i |TP_s| = f\int_0^{8H} p_A^2(t)dt.$$

PROCEDURE

The present research has utilized the chinchilla to test the validity first of the TAWET and then of the EAWDET. Monauralized chinchillas are given various exposures, and both change in behavioral threshold (PTS) and hair-cell destruction are measured, using standard techniques. In order to avoid the question of the appropriateness of A-weighting, we use only a single spectrum of noise: a two-octave-wide band of noise from 700 to 2800 Hz.

EARLIER RESULTS

The results of studies using single uninterrupted exposures are shown in Fig. 1 (Ward et al., 1981). Percentage of destroyed outer hair cells is shown as a function of the SPL of the noise; exposure duration is the parameter. Solid lines connect exposures of constant duration, and the dashed line connects data from exposures of the same energy. That the total-energy theory holds, within limits, for these single continuous exposures, is shown more clearly in Fig. 2, in which the OHC loss is plotted as a function of the exposure in joules/m^2 (the integral of intensity over time). Excluding those exposures that involved sound levels of 114 dB or above, which produced more damage than would be predicted from the other data, presumably because some critical point has been exceeded so that damage is due primarily to direct mechanical action (acoustic trauma) rather than to slower biochemical processes, it can be seen that results support the TAWET, the percent destroyed hair cells being given by $\%DOHC = \sqrt{E/25}$. So when the auditory system is given no opportunity to recover (apart from a no-oftener-than-daily 20-min period during which threshold shifts are measured), damage is indeed determined by the total energy of the exposure. The OHC destruction doubles for each four-fold increase in energy--i.e., if duration is held constant, then the damage is proportional to the pressure, as Kraak proposed. (However, his TAWPT theory is incorrect, because damage is also proportional to the square root of exposure time.)

However, if considerable recovery is permitted between noise bursts, the damage is reduced. This is shown by the filled circle on Fig. 2, which indicates the destroyed OHC count when the exposure consisted of 22 10-min 114-dB noise bursts over a period of 11 weeks (i.e., two per week) instead of a single 220-min exposure at 114 dB (the open circle that is connected to the filled circle by a vertical line): instead of 20% OHC destruction, only 4% were destroyed. So the total-energy theory cannot be used in its most general form.

Having established that the TAWFT is correct for single exposures but not for repeated ones, we now are attacking the FAWDFT. The first experiment, reported earlier (Ward et al., 1982), compared the effects of 9 weeks of exposure for 8 h to 92-dB noise on Monday through Friday (9x5x8=360h) to those produced by the continuous 360-h (15-day) exposure. Results (the filled squares in Fig. 2) showed that the damage was reduced by a factor of two, again implying that the TAWFT is incorrect.

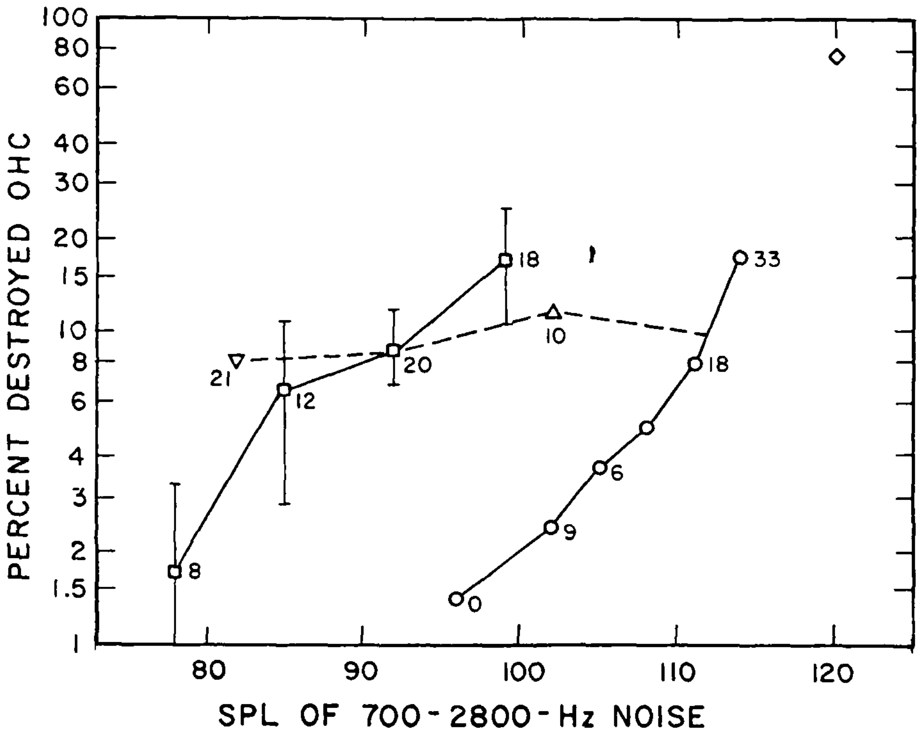

Fig. 1 - Median percent destroyed outer hair cells in groups of chinchillas given single exposures to various levels of 700-2800-Hz noise. Exposure durations are indicated by the following symbols: diamond, 22 min; circle, 220 min; erect triangle, 2200 min (1.5 days); square, 15 days; and inverted triangle, 150 days. Group interquartile ranges are shown for the 15-day data.

MOST RECENT RESULTS

Whether or not the EAWDET is usable was addressed by the latest exposure. Instead of 36 h of continuous exposure at 102 dB (equal of course to 360 h at 92 dB), Group 66 animals were exposed for 48 min per day, Monday through Friday, for 9 weeks. If the EAWDET is correct, the same damage should be produced as by the same pattern of 480-min exposures at 92 dB.

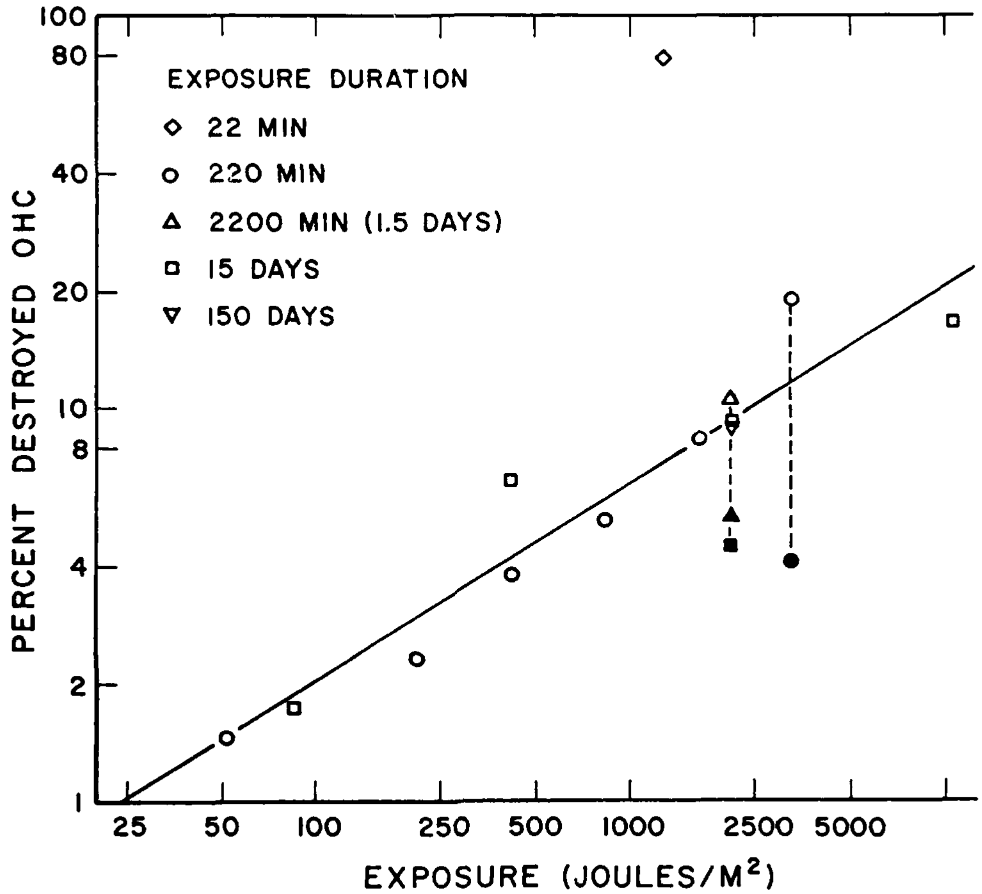

Fig. 2 - Relation between median outer-hair-cell destruction and total energy of the exposure. Single continuous exposures are indicated by open symbols, interrupted exposures by filled symbols.

The filled triangle in Fig. 2 shows that this was indeed the case. Again the damage was reduced by a factor of 2, which can be regarded as a reduction in effective level of 6 dB. Figure 3 shows the distribution of number of destroyed hair cells for all individual animals in the relevant continuous-single vs. daily exposures. The scatter of points obviously implies that it would have been desirable to have more animals per group, but the data clearly indicate that as a first approximation, 45 daily exposures produce less damage than a concentrated single exposure (dividing animals at 500 DOHC, single exposures produced a greater proportion of losses above this figure than did the daily exposures,

significant by chi-square at about the .02 level), and that it makes no difference whether the daily exposure was for 480 min at 92 dB or 48 min at 102 dB.

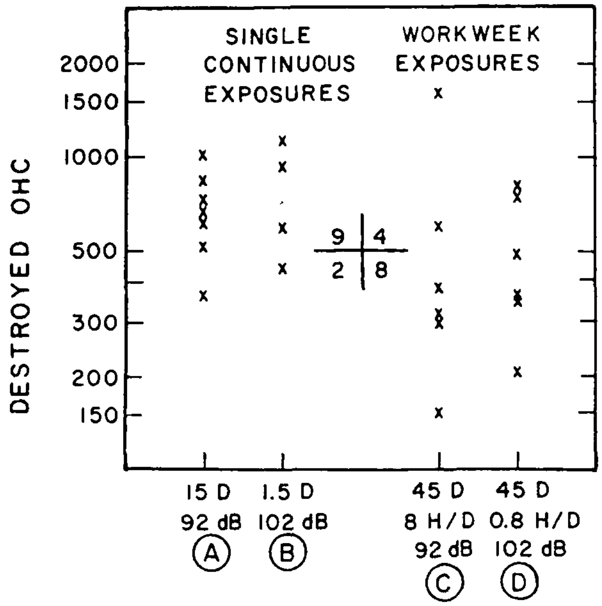

Fig. 3 - Scattergram of individual values of destroyed OHC for animals given steady (groups A and B) or interrupted (work-week; groups C and D) exposures to 700-2800-Hz noise. Total energy of each exposure was 2100 joules/m^2.

DISCUSSION

These results, therefore, provide some support for the FAWDET and consequently for the use of the 3-dB-per-halving trading relation between intensity and time utilized by ISO/1999, rather than the 5-dB-per-halving adopted by EPA for assessing industrial noise exposures. Note, however, that only a single uninterrupted exposure was given on any day. Whether breaking each daily 48 min of 102 dB down into 10 4.8 min noise bursts separated by 48 min of quiet will provide a significant reduction in damage will be tested in the next group of animals; if not, then the conclusion is unavoidable that, at least in the chinchilla, the FAWDET is a viable principle. In that case, the ISO 3-dB trading relation of equal energy should be adopted by regulatory agencies unless it can be shown somehow that the chinchilla is completely different from man in this respect.

There is, however, some evidence that man benefits more from interruptions in the noise than does the chinchilla. This is underscored in the present case by the course of recovery from TTS (or CTS) displayed by these animals. Although the maximum TTS immediately after exposure, at 2 and 4 kHz, was only about 30 dB, a value from which humans nearly always fully recover in 23 hours (especially when the exposure was short but intense), the chinchillas showed only slight recovery even after a full weekend away from the noise. Figure 4 shows the course of the average

TTS, over the 9-week exposure period, measured immediately after the daily 48-min exposure and after a weekend of recovery. It can be seen that although the TTS at 1000 Hz disappears over the weekend, the TTS at 2000 Hz drops only from 30 dB down to 15 dB, and at 4000 Hz there appears to be little recovery at all.

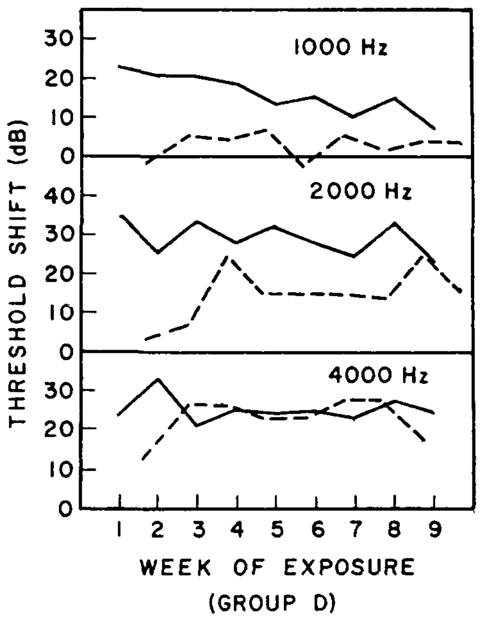

Fig. 4 - Threshold shifts in the chinchilla immediately after a daily 48-min exposure to 700-2800-Hz noise at 102 dB SPL, averaged over Monday through Friday (solid curve) and on Monday morning after a weekend of recovery (dashed curves).

Indeed, even the 40 days of quiet following the final 48-min exposure, before sacrifice, produced little recovery, as shown by Fig. 5. Here are displayed the average CTS audiograms immediately after exposure and after a weekend of recovery, and the PTS existing at the end of the experiment. The top panel shows the 48-min-daily-exposure group, the lower panel the 480-min group. In both cases, recovery beyond a week or so after completion of exposure was essentially nil. Reservations as to the applicability of the present results to man are therefore justified.

The irrelevance of the maximum TTS that the animals had experienced to the development of PTS is also shown by the fact that although the single-continuous exposures produced drastically higher ATTSs than the daily exposures (60 dB vs. 30 dB), the PTSs were essentially equivalent. Indeed, the PTS produced by 45 48-min exposures at 102 dB was slightly greater than that generated by the equivalent single-continuous exposure, even though the hair cell destruction was smaller. The lack of a clear relation between PTS and OHC destruction was confirmed by comparison of individual PTSs and OHC counts; correlations were not significantly different from zero, as earlier results from our laboratory and from all others employing chinchillas have indicated rather unequivocally. Noise produces hair-cell damage and PTS, but it is apparently not the case that hair-cell damage produces PTS.

CONCLUSIONS

Studies of hair cell damage produced in the chinchilla by daily

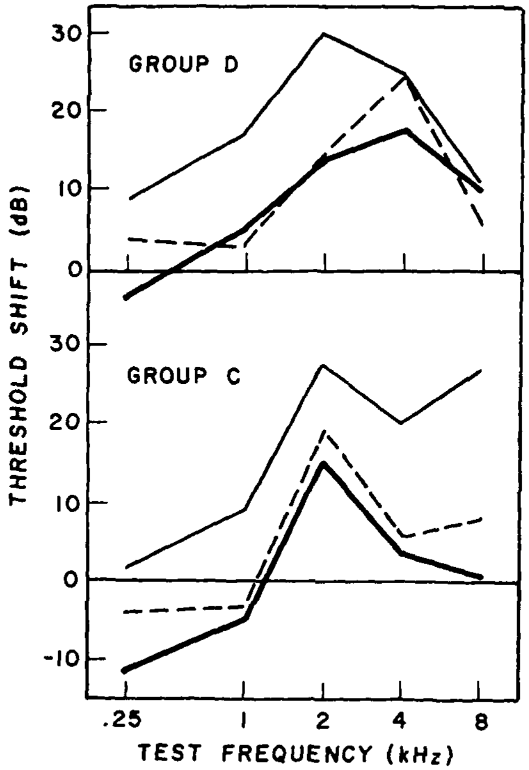

Fig. 5 - Median threshold shifts at the major test frequencies immediately after the daily exposure (thin solid lines), after a weekend of recovery from 5 days of repeated exposure (dashed lines) and 5 weeks after cessation of exposure (heavy solid lines). The upper panel shows data for 48-min daily exposures at 102 dB SPL, the lower panel analogous data for 480-min 92-dB exposures.

ACKNOWLEDGMENT

This research was supported by NIH Grant NS 12125.

exposures to noise indicate that a significant reduction in effect is produced relative to the damage produced by a single continuous exposure whose length equals the total of the daily exposures. Therefore the total-energy theory is not applicable to ordinary real-life situations. However, equivalent damage was produced by daily 480-min 92-dB and 48-min 102-dB exposures, which supports the equal-energy theory. Whether or not interruptions of exposure within the workday will provide additional amelioration of effect remains to be determined, as does the question of the appropriateness of the chinchilla as a model, in view of the fact that even moderate values of temporary hearing losses recover much more slowly in the chinchilla than in man.

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Team No. 2

Noise and Communication

Chairman: J.C. Webster (U.S.A.)
CoChairman: T. Houtgast (The Netherlands)

Invited Papers on Specific Topics

Communicating in Noise, 1978-1983.

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INTRODUCTION

To set the stage for a review of the English language literature in the field of communicating in noise in this, the Fourth International Congress of Noise as a Public Health Problem, I would like to review the treatment of this subject for the first three conferences in 1968, 1973 and 1978. The 1968 conference was financially supported by the U.S. Public Health Service and sponsored by the American Speech and Hearing Association (ASHA) through the associate secretary of ASHA, W. E. Castle who is currently the director of the National Technical Institute for the Deaf in Rochester, New York. The five-man project committee were all audiologists and/or psychoacousticians and included I. J. Hirsh who was also gave the summary of one of the five "panel" sessions. Dr. Hirsh is currently the director of research at the Central Institute for the Deaf in St. Louis, Missouri. Three papers were given in the general field of communicating in noise; one by J. M. Pickett currently the director of the Sensory Communication Research Laboratory at Gallaudet College in Washington, DC; a second by J. Flanagan (of the Bell

Telephone Laboratories) and H. Levitt, currently director of the Graduate Program in Speech and Hearing Science at the City University of New York; and the last by your speaker, J. C. Webster. I am taking all of this time to identify the names and institutions involved in the communication-in-noise-panels of the 1968 conference before I add that not one mention was made of 1) the effect of noise induced hearing loss on the perception of speechor 2) the possible interaction of hearing-impairment and listening in noise. For details, see Ward & Fricke (1969).

The fact that the second congress even happened was due in part to a breakfast meeting of Dr. W. Dixon Ward, Dr. Jerry V. Tobias and Dr. J. C. Webster in Denver, Colorado at the fall meeting of the Acoustical Society of America in 1971. The establishment of the Environmental Protection Agency's Office of Noise Abatement and Control and the passage in 1972 of Public law 480 (on noise control) assured the financial success of the 1973 Dubrovnik Congress. Did the subject matter of communicating in noise change? Your speaker was again fortunate enough to be on the program planning committee and although the number of "speech" papers remained at three the interaction of listening in noise and hearing impairment was finally "admitted into evidence". In my summary paper Webster (1973), I cited the work of Tillman, Carhart and Olsen (1970), and said "...results show both a hearing deficiency penalty and an equipment-imposed (hearing aid) penalty...when listeners are placed in competing message listening conditions...bad news for people incurring noise-induced hearing losses...they have more difficulty...in cocktail party environments (and) cannot look forward to a hearing aid to help equalize their...disadvantage." Tobias and Irons (1973)

devote one section of their paper on learning the "Reception of Distorted Speech" to "Non-Normal Hearing" and say that, "the hard-of-hearing person may have a greater problem of learning to understand distorted speech than the normal-hearing listener..." and suggest that "...the results of some audiometric tests of the ability to understand speech that is immersed in noise may be more a function of learning than of hearing." The third paper, Kuzniarz (1973), is entirely on hearing loss, speech intelligibility and noise. He concludes by noting that "...since 1968 the extent of NIHL (noise induced hearing loss) has been tentatively estimated in my country (Poland) on the basis of mean hearing loss at frequencies of 1,000, 2,000, and 4,000 Hz, as being the most important for speech intelligibility in everyday conditions."

At the 1973 Congress the formal structure of teams was set up to coordinate or at least keep the information flowing among researchers throughout the world in specialized areas of noise as a health problem. Team 2, Noise and Communication was co-chaired by J. C. Webster & J. J. Kuzniarz. The latter subsequently resigned. One of the major tasks of the teams was to organize the presentation of papers at subsequent congresses.

In this manner the choice of subject matter was determined by what research was being done and the interests and organizing abilities of the team chairmen. At the 1978 Congress, Pearsons (1980) summarized the work in the field of noise and communication since 1973. He divided the subject into four parts; speech level measurements, speech perception by the aged and hard of hearing, intelligibility test development, and noise measures for assessing speech interference. Two other subject matter areas were covered by papers

at the congress; 1) group hearing aids and 2) the effects of wearing hearing protectors on the perception of speech and warning sounds. Of the six invited papers published in the Proceedings, see Tobias, Jansen & Ward (1980), three dealt with interactions between hearing impairment and listening in noise. Most of the poster papers, not published in the Proceedings, dealt with this subject and have subsequently come out in other publications. The majority of these originated from the Netherlands and form the basis for the classic paper in the field Plomp (1978) entitled "Auditory handicap of hearing impairment and the limited benefit of hearing aids". I will devote a considerable proportion of my time discussing this paper since it proposes a theory of the interaction between hearing impairment and permissible levels of noise for both unaided and (hearing) aided speech reception.

It would appear then that over the 15 year span of these specialized congresses the inherent interest of the originators in 1968 has been fulfilled. In 1983, fifteen years after the first conference, the original organizer/participants are either directors of, or directors of research, at, the major institutes for deaf education in the USA and none are any longer active in organizing these congresses. Yet the most devastating aspect of noise is the limitation it puts on communicating and it affects hearing-impaired people to a much greater extent than it affects normal hearing people. It imposes extraoridinary noise control problems for any room, meeting place or auditoria where hearing-impaired and/or deaf people assemble. The problem is now being actively pursued by well qualified, multidisciplinary scientists around the world. Just fifteen years ago these same scientists, or their mentors, were researching normal

hearing people almost exclusively even in laboratories associated with institutes for the deaf. I would like to think that these congresses and the teams of people who have originated them and kept them going can take some credit for focusing psychoacoustic noise research into speech perception problems of the hearing impaired.

MEASUREMENT METHODS, Physical

From time immemorial there have been two methods of determining how intelligible speech is in noise, called 1) objective or physical methods and 2) subjective or psychophysical methods, i.e., using human subjects as listeners. Progress has been made on both in the last five years. The oldest and most used or at least most discussed physical method is the Articulation Index (AI) first proposed by French & Steinberg (1947), modified by Beranek (1947) and Fletcher & Galt (1950), standardized by Kryter (1962a; Anon, 1969) and validated by Kryter (1962b) and questioned by about everyone, see in particular Licklider (1959). The major attempts to expand the usefulness of the AI during the last five years have been to include the hearing level (loss) of the listener as part of the noise (see Braida, Durlach, Lippmann, Hicks, Rabinowitz & Reed, 1979; and Skinner & Miller, 1983) and/or to account for the general proficiency of the listener (see Dugel et al., 1980; and Pavlovich, 1982). Skinner and Miller (1983) *state*, "When the frequency-gain characteristics and maximum power output of a (master hearing-aid) are set to shape the speech spectrum (at the most comfortable listening level) within each (of 7 sensorineural) listener's auditory area, they all obtained the highest score for (Pascoe (1975)) words.. in quiet and in speech shaped noise with (a 4.5 vs a 3.5, 2.5 or 1.5 octave) bandwidth (centered at 1280 Hz)." The results were well correlated, 0.77 - 0.90, with the AI.

Dugal et al., (1980) state, "... the proficiency factor... was used merely as a fitting constant (nevertheless) there are ample precedents ... (and) it is possible that some of the negative results... (with) impaired listeners have resulted from a failure to consider (it)...." Pavlovich (1982) found "that the proficiency factor is not frequency independent.... it is substantially reduced for frequencies where hearing threshold is elevated."

Also in the last few years Bowman (1974, 1978) has criticized the use of the multiple correction factors introduced by Kryter (1962a) into the AI calculation scheme and suggested returning to "first principles."

Two different approaches have been taken. Steeneken and Houtgast (1980) summarize their work from 1971 on in the development of a new principle called the Speech Transmission Index (STI). They operate on the speech envelope as opposed to the frequency-intensity domain and have developed a Modulation Transfer Function (MTF) for predicting speech intelligibility from physical measures. Steeneken and Agterhuis (1978) have developed an instrument to determine the STI using Artificial Signals (STIDAS). Over the last five years they and their colleagues have generalized the use of the MTF to calculate the STI for rooms of various size and shapes, see Houtgast, 1981; Houtgast, Steeneken and Plomp, 1980a, 1980b; and Wattel, Plomp, van Rietschote and Steeneken, 1981. The STI accounts for many factors which may be considered noise as far as speech intelligibility is concerned, in particular non-linear distortion and reverberation. The STI and MTF are very valuable tools and we at these Congresses are fortunate to have been kept up to date on their development and use by the cochairman of this team on Noise and Communication, Dr. Tammo Houtgast.

Another approach to account for the effects of reverberation on speech intelligibility, especially in large rooms or auditoriums, has been developed by Lochner & Burger (1958, 1959, 1960, 1961, 1964). They assume there are beneficial reflections (up to 95 msec) that add to the intelligibility of speech. They called this approach the signal-to-noise ratio, usually abbreviated S/N. The novel additions to the usual S/N is that S contains both the speech that arrives with no reflections plus any reflected speech arriving within x milliseconds. And the N includes ambient background noise plus speech that arrives at any time greater than x milliseconds. Lochner and Burger say x equals 95 milliseconds. Latham (1979) in an extensive review (119 refs), proposed a modified version of the S/N where "ambient noise is no longer considered in terms of its steady state characteristics but... in terms of its transient and spectral characteristics given by the concept of the L_{10} PNC (Preferred Noise Criteria; Beranek, Blazier and Figurer, 1971) level." Latham (1979) also cites many other references who have differing ideas on the value, in milliseconds, of the benificial vs the detrimental reflections on the speech. Quoting from Latham, "For detrimental reflections Niese (1956a, 1956b, 1957) proposed 33 msec, Thiele (1953) and Meyer & Thiele (1956) proposed 50 msec while Lochner & Burger proposed 95 msec. In contrast, Mankovsky (1971) and Kuttruff (1973) imply that all reflections may be detrimental to speech intelligibility resulting in a detrimental limit of 0 msec." Thompson, Webster & Gales (1961) also note that "... live speech was less intelligible and less preferred." where liveness includes "reverberation time and distance between the sound source and listener."

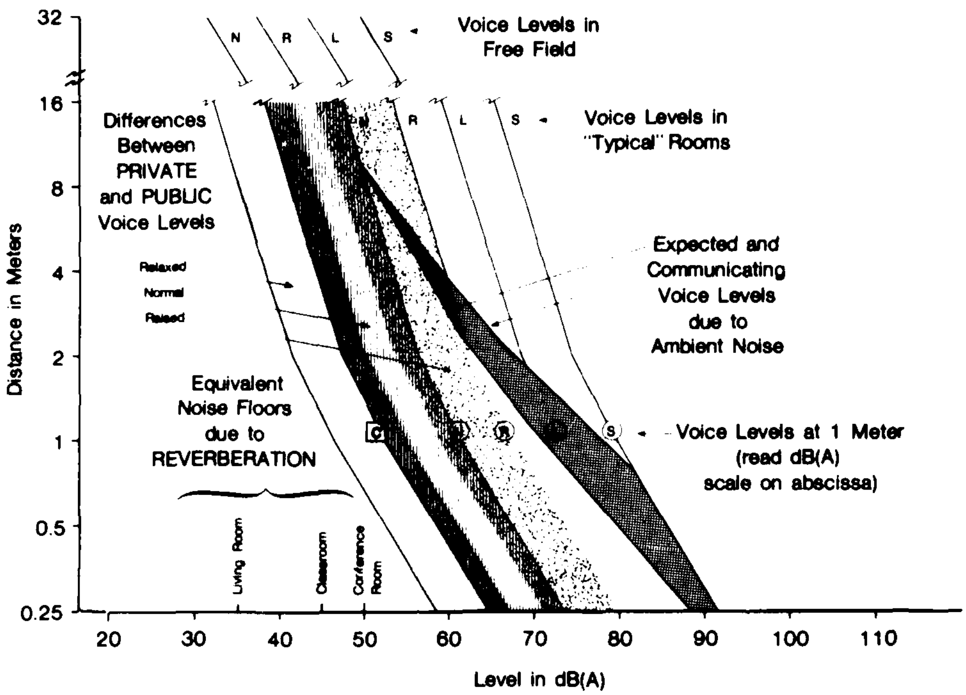

Fig. 1 - Relationships among ambient noise levels, distances between communicators and voice levels of talkers for satisfactory speech communication in typical enclosed spaces. Although any voice level can be used, in general talkers will unconsciously raise thier voice levels as noise levels, distances between communicators and/or the importance of their message(s) increase. Adapted from Beranek (1947b, 1954), Botsford (1969) and Webster (1969, 1973, 1979).

Before finishing my remarks about physical methods of evaluating the effects of noise on communicating, I should use my paper to this congress, as I have at all previous congresses, to present and/or update my latest Speech Interference Level (SIL) chart. After it was used as the basis for an American National Standards Institute (ANSI) standard in 1977 (see Anon. 1977) it was evaluated and found generally acceptable by Waltzman and Levitt (1978) and its general weaknesses pointed out by Houtgast (1980). The latest revision of the chart is shown in Figure 1. Revisions include: (1) a range of relaxed, normal and raised voice levels to reflect differences in private conversation and public communications based on

data of Houtgast (1980); (2) a different rate of fall off of speech level with distance based on typical reverberant room characteristics instead of on a free field, based on Beranek (1954); (3) equivalent noise level floors for living rooms, classrooms, and auditions based on reverberation, see Houtgast (1980); and (4) a downward (-3 dB) shift of the voice level reference lines at one meter to account for the differences in rms SPL and dB(A) as recently reiterated by Steeneken and Houtgast (1978).

MEASUREMENT METHODS, Psychoacoustic

Since my time and your patience is running out in this review, let me cover one major topic, development and advances in the state of the art of speech discrimination and discrimination testing by essentially begging the question. In 1972, I put together a compendium of speech tests, Webster, 1972. Berger (1977) supplemented the listing of speech audiometry materials and two extensive reviews of the subject have come out since 1978. Edgerton and Danhauer (1979) have 90 pages on nonsense syllables tests including about 225 references and Mackie and Dillon (1982) have 106 pages with about 350 references on word tests. About a quarter of the references overlap and about 8 percent are in the time-frame 1978-1983. So anyone interested in this (these) subject(s) has four very exhaustive compendia and/or reviews covering at least 500 references of which about 35 cover the five year time span since our last congress. The most novel advances concern the statistical properties of test construction, see Raffin and Thorton (1978), Dillon (1982), and Walker, Byrne and Dillon (1982). One concludes a binomial distribution describes speech discrimination test scores, an efficient test should have equally difficult items and be designed for an 80 per-

cent score, and don't assume that closed-set responses eliminate learning at least on nonsense syllable tests.

Other approaches to test efficiency have been advanced by Plomp and Mimpen (1979) and Sargeant, Atkinson & Lacroix (1979). A myriad of work has come from the Netherlands since 1978 and I will assume Plomp, Houtgast and Smoorenburg who follow me on this program will cover their and their colleagues' materials.

At the last congress, Pearsons (1980) described the development of the Speech Perception in Noise (SPIN) test, see Kalikow, et al., 1977. Elliott (1979) has found that the difference in the perception of the same key word in sentences of high and low predictability develops as a child reaches linguistic maturity at age 15 to 17. Anna Nabelek who also follows on this program verifies experimentally many of the theories the Netherlands gang proposes and generalizes some of the findings of Elliott.

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LITERATURE REVIEW 1978-1983 IN GERMAN LANGUAGE ON NOISE AND COMMUNICATION.

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INTRODUCTION

Research on the disturbance of verbal communication and the disturbance of recognizing alarm signals in noise has been conducted from many different angles. Further, problems are taken up which are presented in the literature as well as the standard problems.

The essential part of the disturbance of speech intelligibility in noise results from the masking effect of the noise. Speech as well as noise in everyday life are fluctuating temporal sounds. Fundamental research on the masking of fluctuating temporal noise was carried out by Zwicker (1982) and Fastl (1982).

Research on sensorial discrimination of information-carrying sound was carried out by Spreng (1981). For the decoding of speech, above all, the dynamics of hearing is decisive (Spreng 1983a). Not only are formant frequencies differentiated and discriminated rapidly (300 ms), the transients, changes in intensity and frequency are also evaluated during the flow of speech.

Verbal communication is necessary in the home, in the environment, on the job and in education. On the job, e. g. in factories, recognizing alarm signals is also of prime

interest. In recent years attempts have been made to determine the influence of speaker, hearer, distance and noise, as well as to establish standards for these dimensions. Communication is influenced by other factors, e.g., by the wearing of ear protectors, by secondary task and by hearing loss. People who are occupied in noise over a long period of time can be impaired in two different ways. Noise can cause deafness, on the one hand, and lead to disorders of voice because of the necessity to speak loud, on the other. Both lead to an impairment in communication.

The very extensive research involving the analysis of speech for voice and speech recognition, and the research on the synthesis of speech with a computer will not be handled here.

AN UNIFORM CONCEPT FOR THE MEASUREMENT AND ASSESSMENT OF NOISE.

An attempt has been made in recent years to come to an *uniform concept for measuring* and assessing the effect that noise has on people. This attempt deals with measurement and assessment in a multitude of homes (from inside and outside), places of education and in working areas (Lazarus 1977). With the aid of this concept, sound level can be measured and assessed with the same procedure, independent of the source of noise, place, type of activity and the strength of the noise level. The rating level (L_r) determined like this, can therefore be compared with other rating levels. Also, an easy comparison with established limiting values is possible.

The principle of measurement and assessment reads as follows:

- The place of measurement is stationary.
- The following will be determined (according to DIN 45645, parts 1 and 2).
  - The A-weighted equivalent-energy continuous noise level ($L_{eq} = L_{Am}$)
  - Correction for the impulsive noise (K_I) and the tonal noise (K_T) in the assessment period. The correction of the impulsive noise is the difference between the equivalent continuous A-weighted sound level with

time weighting impulse (L_{AIm}) and the equivalent continuous A-weighted sound-level (L_{Am})
$K_I = L_{AIm} - L_{Am}$, the correction of tonal noise is estimated (K_T = 3 or 6 dB). If necessary, further corrections e.g., for the influence of low-frequency noise, can be made.

- The rating level is then the sum:
  $L_r = L_{Am} + K_I = L_{AIm} + K_T$
- The assessment time is, for the working area : 8 hours; for the environment : day: 7°° - 19°°, night: 22°° - 6°°, interim: 6°° - 7°°, 19°° - 22°°.

The negative effects such as serious annoyances, problems with sleeping and resting, neuro-physiological reactions, disturbances in attention and concentration, disturbances in verbal communication and the recognition of signals, disturbances of the acoustical orientation in the environment,ear damage,and disorders of voice should be avoided for the largest number of people involved,by setting reference and limiting values.

To emphasize: This principle for measurement and assessment is valid for millions of jobs and homes where people are more or less disturbed by noise levels from L_r = 40 - 130 dB. By establishing one limit for a living or working area, the quality of this area can be classified regarding the handicap caused by noise and made comparable to other areas.

The assessment of noise in the working area where verbal communication is critical (e.g., at pilot's working place) or in living areas where people's sleep is disturbed by temporal fluctuating noise can, in addition, be taken into consideration with further criteria such as the articulation index (AI) for speech intelligibility, or with a peak level ($L_{AF1\%}$) for undisturbed sleep.

Limiting values that are supposed to insure a certain speech intelligibility are not specifically set in the Federal Republic of Germany. Limiting values for verbal communication can be derived from the areas 'environmental protection' and 'occupational safety' where limiting values are established because verbal communication is necessary (Tables 1 and 2). In this way, a certain speech intelligibility can be insured in homes (during the day), restaurants, auditoriums, offices and conference rooms. Aside from protecting the ear against hearing loss ($L_r \leq 85$ dB)

and the impairment of work efficiency ($L_r \leq 55$, 70 dB), the maximal noise levels for working areas for the disturbance of verbal communication through noise ($L_r \leq 55$, 70 dB) and for occupational safety the recognition of alarm signals ($L_r \leq 85$ dB) are standard.

The limit of 70 dB should make a certain amount of verbal communication possible in rooms where typewriters are used or in factory offices. The limit of 55 dB in lower-noise offices and conference rooms should make a certain speech intelligibility possible. These limits, however, are to be seen as absolute limiting values, which are also technically possible to achieve. For a good to very-good speech intelligibility in conference rooms, for example, this level would have to be undercut by 20 - 30 dB, as can be seen in Table 1 (Jansen 1977).

OCCUPATIONAL ACTIVITY	HIGHEST VALUE L_r in dB	EXAMPLES OF THE ACTIVITY
mainly mental activiy	55	meetings, transactions; telephone and radio centers; technical, scientific areas; writing and correcting difficult texts
simple and mainly mechanized office activities	70	planning; data gathering; typewriting work in a factory office; sales to and waiting on customers
all other activities	85	

Table 1: Rating level (L_r according to DIN 45645, part 2) for the working area which should not to be exceeded (from the Arbeitsstättenverordnung, § 15, from VDI 2058, Blatt 3); as long as no noise containing impulse or tone is present, $L_{NAm} = L_r$ across the assessment time.

ROOMS	Highest values for noise level L_{NAm} in dB			
	VDI 2569 for background noise in office rooms ($L_{AF\ 95\ \%}$)	DIN 4109,5 [1] for noises from household applicances and machinery	VDI 2719 for rooms where noise comes from outside	VDI 2081 [2] for rooms with central ventilation
HOMES				
- day	-	25 - 30	30 - 40	30
- night	-	25 - 30	25 - 35	30
RESTAURANTS	-		40 - 50	40
AUDITORIUMS	-	35	30 - 40	25 - 35
CONFERENCE-ROOMS	30 - 35	35	30 - 40	35
HOSPITALS	-	25 - 35	30 - 40	35 - 40
OFFICES				
- private	30 - 45	35	30 - 40	40
- office for several persons	30 - 45	35	35 - 45	45

1) The level values may be exceeded under some conditions by 5 - 10 dB. 2) The peak levels ($L_{AF\ 1\%}$) should not exceed the given data by more than 10 dB.

Table 2: Highest values for noise level in rooms. The given noise levels are, as a rule, the equivalent continuous sound level (L_{NAm}) (DIN 4109, part 5; VDI 2719; VDI 2081), over the time that the rooms are in use: e.g., living room (day) 6°° - 22°°; (night) 22°° - 6°°; office rooms 8°° - 16°°. The level values in VDI-2569 are background noise levels ($L_{AF\ 95\%}$).

EVALUATION OF VERBAL COMMUNICATION.

Procedures in order to predict speech intelligibility from the physical parameters of speech (speech level: $L_{SA,1m}$; $L_{Soct,\ 1m}$), of noise (noise level: L_{NA}; L_{Noct}) and of room (distance between the speaker and hearer r,

volume V, and reverberation time T) are presented:

- A-weighted signal-to-noise ration (SNA)
- speech interference level (SIL)
- articulation index (AI)
- speech transmission index (STI)

(see Beranek 1947, Kryter 1962, Webster 1969, 1973, Steeneken & Houtgast 1980).

The AI and the STI can be used sensibly, especially in special working areas or auditoriums, when the use of more complicated technical measurement (measurement of spectra and of the reverberation-time at different points) is possible. The SIL-curves are especially well suited for a simple estimated prediction of speech intelligibility. The speech level at a 1 meter distance from the speaker's mouth ($L_{SA,1m}$) (description of vocal effort) is used as a basis. A decrease of the speech level is given in 6 dB/double intervals. This specifies the signal-to-noise ratio (L_{SNA}) for a specific distance between speaker and hearer (r) and noise level (L_{NA}, L_{SIL}). The speech intelligibility (SI) can then be calculated from the signal-noise level for words or sentences. The SIL-curves proceed from a specific speech intelligibility or signal-to-noise ratio. The maximal possible distance (r) for this pre-established speech intelligibility is then be read in the dependence on the existing noise level (L_{SIL}, L_{NA}).

An overview (Lazarus et al. 1984) of SIL-curves from authors or from fixed standards (Beranek 1947, Webster 1969, Kryter 1970, Webster 1973, 1979, ISO 3352, ANSI S. 3.14, DIN 33410) led to the following result: A satisfactory speech intelligibility - the prerequisite for the SIL-curves - is given by an AI = 0.4 - 0.5 (ca. 0.45) or a signal-to-noise ratio of L_{SNA} = 0 - 3 dB (ca. 2 dB) and corresponds to an intelligibility of monosyllabic words of SI = 65 - 75 %. However, the speech levels given by the various authors which were categorized into individual vocal efforts are different. On the basis of newer research projects (Pearsons et al. 1977, v. Heusden et al. 1979, Houtgast 1980), new speech levels were given for 11 different vocal efforts (Table 3). The speech levels have an interval of 6 dB (corresponding to a suggestion by Beranek 1947). The curves, which are based on the experimental results up until now, are given in Figure 1.

Based on the Lombard effect, a speech level range can be given - expected vocal effort - that will probably be used

by the speaker when a noise level is already known.

Vocal effort		Sound level $L_{SAm, 1m}$
whisper		36 dB
soft	speaking	42 dB
relaxed (p)	"	48 dB
relaxed, normal (p)	"	54 dB
normal, raised (p)	"	60 dB
raised	"	66 dB
loud		72 dB
very loud		78 dB
shout		84 dB
maximal shout		90 dB
maximal shout (in individual cases)		96 dB

Table 3: Sound level of the speaker (L_{SAm}) at 1 meter in front of the speaker's mouth for the given vocal effort; p = in private quarters.

Based on the results of Pearsons et al. 1977 and v. Heusden et al. 1979 and on practical examples as well, the range of expected vocal effort was newly developed: The distance used at low noise levels (L_{NA} = 40 - 50 dB) is r = 4 - 8 m for the SIL-curves (Webster 1979, ANSI S. 3.14, DIN 33410); for the SIL-curves in Fig.1, it is 2-3m and obviously more realistic (Lazarus et al. 1984). A trial to establish the maximal noise levels for verbal communication in residential rooms and workrooms with the aid of the SIL-curves was carried out by Lazarus et al. 1984.

Sotscheck 1982a developed a new German rhyme-test for measuring the quality of speech transmission for communication-systems (telephone system). Intelligibility tests with this rhyme-test and nonsense syllables produce less variance, a less distinct learning phase and a better repeatability (Sotscheck 1981, 1982 b). The intelligibility tests were measured for 2 bands (.3 - 3 kHz) and 8 disturbing noises (Sotscheck 1983). In order to achieve the same intelligibility for both bands, the noise level for the band 0.3 - 3 kHz has to be lowered by 1 - 8 dB.

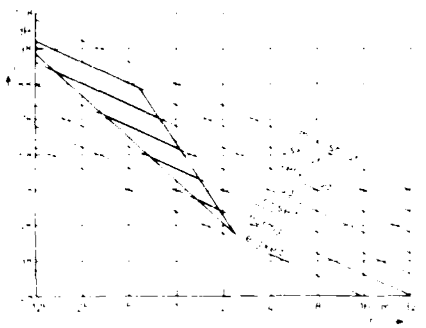

Fig.1: SIL-r-diagram, relationship between the noise level (L_{NA}, L_{SIL} for 0.5, 1, 2, 4 kHz) and the maximal distance between the speaker - hearer (r) for satisfactory speech intelligibility (articulation index AI = 0.45) for different vocal efforts (at normal vocal effort, the speech level is $L_{SA,1m}$ = 60 dB). The cross-checked field indicates the expected vocal effort on the basis of the Lombard-effect (from Lazarus et al. 1984), $L_{SIL} = L_{NA} - 8$ dB.

The masked threshold for the band-limited speech and noise of different spectra but constant level lies at $L_S - L_N = -1$ to -5 dB. The masked threshold for temporal fluctuating noises ($L_{N5\%} - L_{N95\%} > 10$ dB) lies at $L_S - L_N = -5$ to -24 dB. Cakir et al. 1983 investigated the use of the dictating machine for dictating and listening and the necessary signal-to-noise-ratio.

INFLUENCE OF SPEECH MATERIAL AND DIRECTIONAL HEARING ON SPEECH INTELLIGIBILITY IN DISTURBING NOISE.

The impairment of verbal intelligibility in everyday life can be predicted with the aid of speech-audiometry. In addition to the tone-audiogram, the speech-audiogram can be determined for the hard-of-hearing persons in the Federal Republic of Germany.

The tone-hearing loss can be determined from the tone-audiogram. The speech-audiogram is presented monaurally with word-numbers (DIN 45621) and monosyllabic words (DIN 45621). The speech-audiogram can also be determined using sentences (DIN 45621, part 2), although it is questionable whether a better prediction of speech intelligibility in every day life is possible there with. The intelligibility curves for spondees and for sentences are often very similar. Aside from this, sentences can be constructed on very different levels of difficulty (Kalikow et al. 1977). Because of this, the results of speech-audiometry when sentences are used do not allow a very strong argument.

For example, it was shown (Lazarus & Lazarus-Mainka 1979) that the masked threshold for main sentences, as well as the main

sentences and clauses of sentence structures, differed by 6 dB. The masked threshold for individual sentence parts such as subject, predicate, object lie at 6, 3.5, 9.5 dB lower than the threshold for the whole sentence. Even though the predicate is spoken equally loud, it is the worst understood part of the sentence.

Platte 1979, 1978, measured the interdependence of the results of a speech test with selected speech material (numerical words, monosyllabic words, triple repetition of monosyllabic words) and the type of noise (white noise, simulated speech-noise). Large variances can be avoided with triple repetition (e.g., house, house, house). As long as no interaural processes are involved, the slope of the intelligibility function with speech level is maximal when the power density spectra of the signal and the noise are identical, e.g., by simulated speech-noise (e.g., for monosyllabic words 7 % per dB, for numerical words 17.5 % per dB).

A better prediction of everyday intelligibility can be obtained when further factors such as noise, directional hearing and monaural and binaural hearing are included. The influence of different geometric arrangements of signal and noise sources and of the transmission characteristics of the external ear in relation to the subject, can be included only when the person is tested with spatially separated signal and noise sources in an anechoic room.

Platte 1979, Platte & Hövel 1980 compared the results of binaural speech intelligibility tests obtained under different test procedures. When the masked threshold is measured according to the Bekesy-procedure, the variance is higher than by determining an intelligibility of 50 % by counting the understood words at a constant level (Platte 1979).

When considering communication in noise, the results of the intelligibility difference (ILD) is of prime interest. The ILD indicates by how many dB the speech-to-noise ratio can be lowered in relation to the reference situation (ILD > 0) in order to obtain the same intelligibility (50 % of the three monosyllabic words).

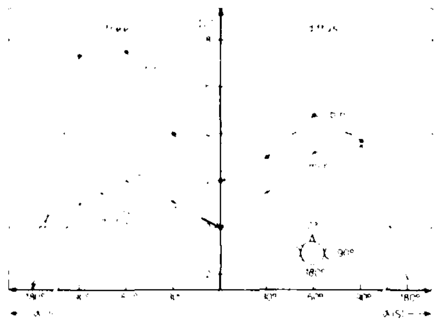

Fig.2: Intelligibility level difference (ILD) of three monosyllabic words for the different directions from which the speech is radiated from the loudspeaker (α); radiation of noise (L_{NA} = 65 dB in free field from 180° (N_{180}), for the diffuse field from 6 loudspeakers (N_d) (from Hövel & Platte 1980):

sound field:	hearing:	noise:	reference:
diffuse	bin.	speech simul. noise	S_oN_d mon.
diffuse	mon.		S_oN_d mon.
free	bin.	"	S_oN_{180} mon.1
free	mon.1	"	S_oN_{180} mon.1
free	mon.2	white noise	S_oN_{180} mon.2

Twelve loudspeakers are set up around the test person. The disturbing noise occurs in a free field from the position 180° (N_{180}). The diffuse noise field is generated through uncorrelated noise which comes from 6 of the 12 loudspeakers (N_d). Speech comes over only one of the loudspeakers (α(S)).
The results are partially given in Figure 2. The ILD-function for monaural hearing could be satisfactorily predicted (Hövel & Platte 1980) with the AI by considering the monaural transmission-function of the outer ear. Hövel 1981 broadened this ear model to include a model of binaural signal processing (from Durlach 1963). In this manner he can also accurately predict the ILD-progression for binaural hearing in anechoic surroundings under the influence of noise.
The higher the signal-to-noise ration in the low-frequency components, the greater the improvement of intelligibility is through binaural processing.

SPEECH INTELLIGIBILITY BY HARD-OF-HEARING PERSONS.

Speech intelligibility, when disturbed by noise, is also influenced by hearing ability. Niemeyer (1983) and Spreng (1983b) listed the factors which are decisive for perception of speech for persons with noise-induced hearing loss. They described this evaluation of hearing ability with the following tests:

1. The tone audiogram shows preliminary damage well. Nevertheless, changes in adaptive ability can be seen without substantial hearing loss (HL $\approx$ 10 dB). In order to follow the envelope of speech, the ability to adapt and readapt rapidly is necessary.

2. The reduced ability of the hard-of-hearing to identify and discriminate short-term intensity-frequency-patterns and temporal fluctuations in frequency and intensity can substantially worsen the recognition of speech.

3. Recruitment impairment causes changes in the hearing characteristic chiefly in the higher frequencies. The relatedness of individual formants for a vowel or for the intensity change from consonants to vowels cause a different excitement pattern and a false perception of speech sounds through the different recruitment curves with hard-of-hearing persons.

4. The hearing loss functions as a low pass filter; surrounding noise, such as traffic noise, is usually low-frequency and is especially disturbing because the remaining lower frequency speech that the hard-of-hearing person can still perceive is masked.

5. The dynamic efficiency and selectivity of the ear is to be tested in that the speech intelligibility test is performed in the presence of party babble.

Fastl & Schorn 1981 and Zwicker & Schorn 1982 can show that the discrimination of level differences, the temporal resolution of the ear and frequency selectivity is reduced in hard-of-hearing persons.

In the assessment of environmental noise (air noise) Müller-Limmroth (1979) includes the speech intelligibility of the slightly impaired hard-of-hearing (hearing loss < 20 dB at $f \leqq 2$ kHz, $\leqq 40$ dB at $f \leqq 4$ kHz). About 50 % of persons aged 63 have a hearing loss of this caliber. In order to achieve equal intelligibility, the noise level must be L_{NA} = 5 - 10 dB lower for the slightly impaired than for persons with normal hearing. Inside a room, an AI should not fall below 0.7 (Weber et al. 1980).

SPEECH INTELLIGIBILITY AND SECONDARY TASK.

Persons on the job or working in the home who want to perceive verbal information must concentrate on both activities: perception of speech and the task with which they are involved.

In two experiments, persons were presented with sentences ($L_{SA} \approx 65$ dB) at noise level ($L_N = 55 - 85$ dB). The persons had to perform simultaneously either a sorting task (Lazarus-Mainka & Sasse 1981) or a visual memory task (Hörmann & Ortscheid 1981). The intelligibility as well as the sorting performance decreases as the signal-to-noise ratio decreases. Speech intelligibility decreases by 5 - 20 % when the difficulty of the sorting and memory tasks increases (see Figure 3).

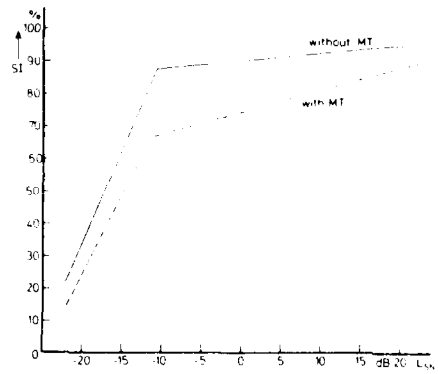

Fig.3: Speech intelligibility SI (regression lines) in dependence on the signal-to-noise ratio (L_{SN}) with and without a visual memory task (MT), (from Hörmann & Ortscheid 1981).

VERBAL COMMUNICATION AND THE WEARING OF EAR PROTECTORS.

Many industrial workers report again and again that the wearing of ear protectors hinders verbal communication in working areas. These statements contradict research results which show an improvement in intelligibility at high noise levels and wearing ear protectors. In these experiments, speech is presented over a loudspeaker, but verbal communication takes place in a speaker-hearer interaction where the speaker speaks spontaneously what the hearer is supposed to understand. In the following experiment (Hörmann et al.1981, 1982), it is asked: Does the degree of intelligibility change when the speaker and hearer are in actual conversation and both are wearing ear protectors in the same noise conditions?

Both conversation partners sat at a distance of 1.5 m facing each other. They were separated by a translucent curtain (that did not hinder sound) in order to prevent lipreading. The noise level was set at L_{NA} = 76, 84, 92 dB. A common ear plug was used with a noise reduction of R = 20 - 30 dB - in the frequency-range of interest.
The speaker and hearer both either wore or did not wear ear protection. The types of speaker-hearer interaction varied: the speaker read texts, monosyllabic words, sentences and told picture-stories. Only the average values for these 4 speech samples are calculated and given here.

The main results are: when a speaker wears ear protection, he/she speaks at L_{NA} = 92 dB about 4 dB softer. That a person speaks louder in noise than in quiet is well known and called the Lombard-effect. That a person wearing ear protectors in noise speaks softer is explained in compliance with the Lombard-effect in that the person perceives his/her own voice as being louder than it really is because it is fed back through auditory bone conduction.

Eventhough the speaker speaks louder as the noise level increases, the speech intelligibility decreases when ear protectors are worn and the noise level increases. The difference in intelligibility in the noise condition L_A = 92 dB is especially noteworthy. Here, persons without ear protectors still understand ca. 70 % of the verbal information; when both hearer and speaker wear ear protectors, the hearer understands 40 % less (Figure 4).

When the conversation partners both wear ear protectors, the words are spoken ca. 20 % faster. The speech pauses are 25 % shorter. The interaction-time (the time between reading the individual words or sentences) increases sharply as the noise level increases. In this period of time, the hearer has to perceive the verbal cue, identify it and repeat it. When ear protectors are worn, the interaction-time increases by ca. 20 - 30 %.

In a laboratory experiment with 5 different ear protectors, Bratge 1983 gave the subjects tasks where verbal communication was necessary. After the experiment, the subjects were asked 17 questions about the impairment through ear protectors. Three factors are derived from the factor analysis: effect of ear protection on speech intelligibility, ear protection as a foreign body, and as a physiological handicap. The 3 factors

account for ca. 60 % of the variance and 40 % of this variance is accounted for by the first factor (verbal communication). The 5 ear-protection situations are compared pairwise with one another. The most pleasant ear protectors were the wadding or plug with low noise-reduction. Plugs with higher noise-reduction and muffs rated the worst.

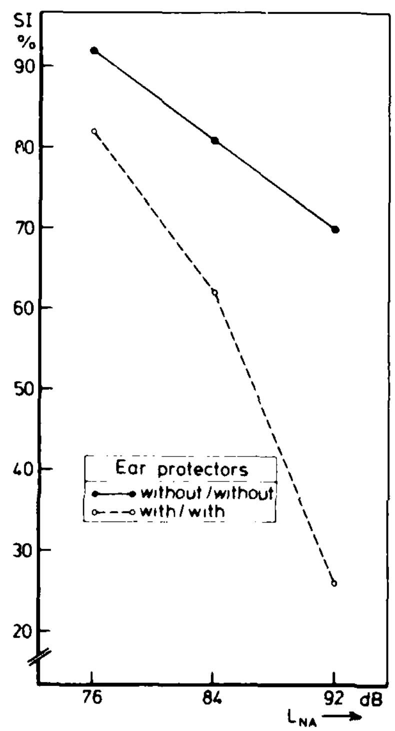

Fig.4: Speech intelligibility (SI) in correctly understood verbal cues in dependence on noise level (L_{NA}), where both communication partners wear (with/with), or both do not wear (without/without) ear protection (from Hörmann et al. 1981, 1982).

Fröhlich (1978) investigated sentence intelligibility on persons with slight hearing loss. Without ear protection, the intelligibility at noise and speech level L_A = 86 dB lay between 90 - 100 %. When ear protection was worn, the intelligibility sank to 52 - 83 %. If verbal communication while wearing of ear protection is assessed according to measured intelligibility and subjective evaluation, it can be concluded that: verbal communication (speaker/hearer interaction) for normal-hearing persons and understanding verbal information (from a loudspeaker) by slightly impaired persons worsens

as the noise reduction of the ear protection increases. This means that the ear protector should be chosen that is necessary to reduce the noise level just enough to protect the ear - in order to prevent overprotection (Burkhardt 1979; Abel et al. 1980, VDI 2560, Lazarus et al. 1984).

RECOGNITION OF SIGNALS WHILE WEARING EAR PROTECTORS.

Two reviews (Lazarus 1980, 1981) deal with the influence of ear protection on the recognition of signals and speech, for normal-hearing and hard-of-hearing persons, on directional hearing and on verbal communication. The experiment from Lazarus & Wittmann 1980, and Lazarus & Wittmann 1983 deals with the recognition of signals while wearing earplugs and muffs in noise levels of L_{NA} = 80 - 105 dB. The signal was a Typhon-signal commonly used by trackwork to warn against oncoming trains; the noises were commonly occurring noises in the field with different spectra. The criterium for hearing efficiency with ear protection in contrast to hearing efficiency without ear protection is the masked threshold (50 % heard signals). The results of the hearing trials are: If persons with normal hearing wear earplugs, the hearing efficiency, on the average, improves slightly. The masked threshold decreases by ΔL = 0 - 2.5 dB when the person wears plugs in comparison to the unprotected ear. If the persons are wearing muffs, the hearing efficiency is lowered, on the average. The masked threshold increases by ΔL = (0 - 6) dB.

The change in hearing efficiency due to ear protectors is even stronger at noise levels over L_{NA} = 90 dB. Hearing efficiency while wearing ear protectors is especially strong with noises at high sound levels at frequencies under 500 Hz (Figure 5). With such noises, the masked threshold can show a decrease of ΔL = 2.5 dB while wearing earplugs, in comparison to an unprotected ear; the masked threshold increases by ΔL = (4.5 - 6) dB while wearing common earmuffs. The change in the masked threshold by wearing ear protection is the least when the noise consists mainly of higher frequencies and lies by ΔL = (- 1 to 1) dB. The percent of heard signals is given in Figure 6 for the 4 noises and the low frequency noise in the 3 ear protection situations. The results of the hearing trials can be explained by remote

masking. Whether or not an ear protector increases the perception of signals in certain noises can be estimated with the procedure for calculating loudness described by Zwicker 1967 (Mayr 1980; Wittmann & Lazarus 1980).
The results until now have dealt with normal-hearing persons. The hearing trials with more or less serious hearing loss were carried out only with earplugs. These subjects were assigned to 3 groups of increasing hearing loss (HL) - averaged across the frequencies 0.5 / 1 / 2 kHz.

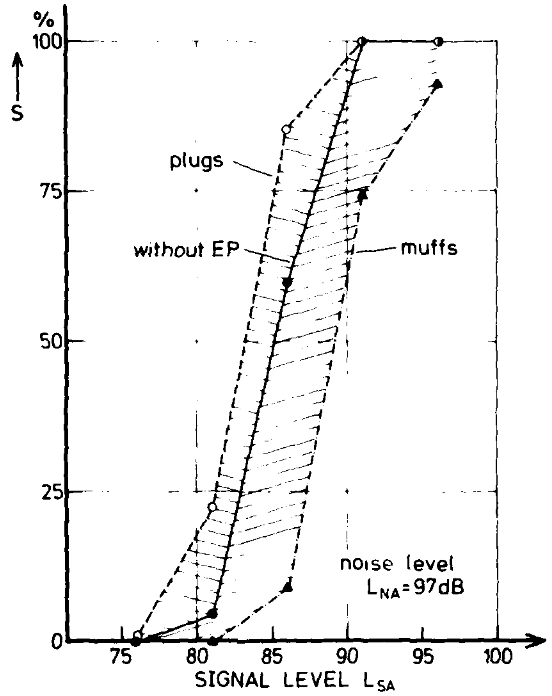

Fig.5: Percent of heard signals (S, Typhon) the signals were masked by a low-frequency noise (noise for railroad track-workers, L_{NA} = 97 dB); the signal level is L_{SA} = 76 - 96 dB; Persons wearing plugs, muffs or no ear protection (without EP) (from Lazarus & Wittmann 1983).

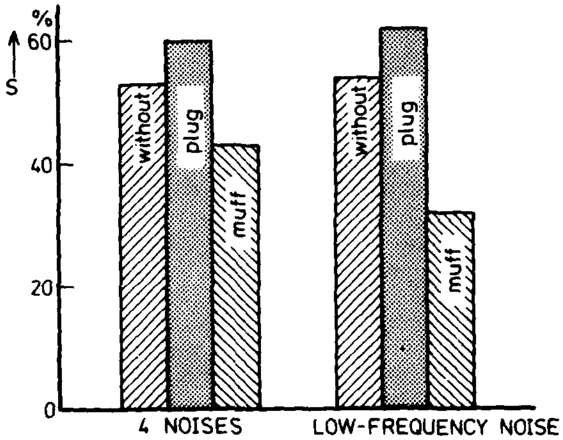

Fig.6: Percent of heard signals (S, Typhon) for 4 typical track-work noises with the noise level L_{NA} = 96 dB; the signal level is L_{NA} = 76 - 96 dB; persons wearing ear protection or no ear protection (from Lazarus & Wittmann 1983).

For the 4 noises of different spectra, the hearing efficiency worsens with increasing hearing loss when no ear protection is worn. While wearing the earplugs, the hearing efficiency decreases more sharply with increased hearing loss. The group with the greatest hearing loss (HL = 40 - 83 dB) when compared to the normal-hearing group (HL = 2 - 12 dB) had a raised masked threshold by Δ L = (4-6.5 dB) while wearing no ear protection. It raised to Δ L = (6.5 - 12) dB when earplugs were worn. The correlation between the masked threshold and hearing loss lies between r = 0.74 - 0.85. If hearing loss is less than HL = 20 dB, the average hearing efficiency while wearing plugs is equally good or minimally better than when the ears are unprotected. However, when the hearing loss exceeds HL = 20 dB, hearing efficiency, as a rule, is less when earplugs are worn than when the ear is unprotected (Figure 7).

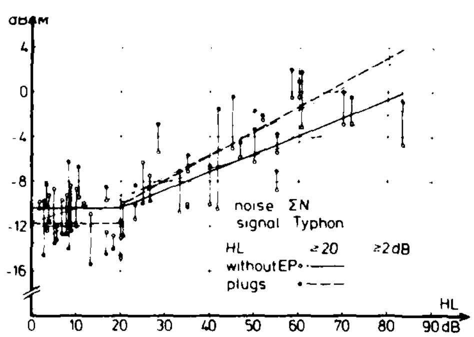

Fig. 7: Masked threshold (M = L_{SA} (50 % heard signal) - L_{NA}) for Typhon signals (signal level L_{SA} = 81 - 96 dB) in dependence on hearing loss (HL) (HL for 0.5, 1, and 2 kHz); masked noise: 4 typical trackwork noises (L_{NA} = 96 dB) the persons wear plugs or no ear protection (EP) (from Lazarus & Wittmann 1983).

PERCEPTION, ASSESSMENT AND CHOICE OF ALARM SIGNALS.

The perception of signals that are disturbed by noise can be best described by the masked threshold (Zwicker 1967). Some of the occupational accidents can be explained by a masking of acoustic signals (Eickelpasch 1978).

The perception of signals can be guaranteed when the octave sound pressure level lies 10 dB over the masked threshold (DIN 33404, part 1). In order to simplify the on-the-job use

and insure the perception of signals for occupational hazards, the masked threshold is determined from the octave sound level and not - as is common practice - from the third octave sound level. The effect of hearing loss and ear protection on signal perception can be seen in the remote masking of the higher frequencies by the lower frequencies. At 100 dB, remote masking for normal hearing persons lies at ca. 20 dB/oct; for minimal hearing loss, it lies at 6 - 9 dB/oct (Rittmanic 1962) (Figure 8). The simplified masked threshold for acoustic alarm signals is given in Figure 9.

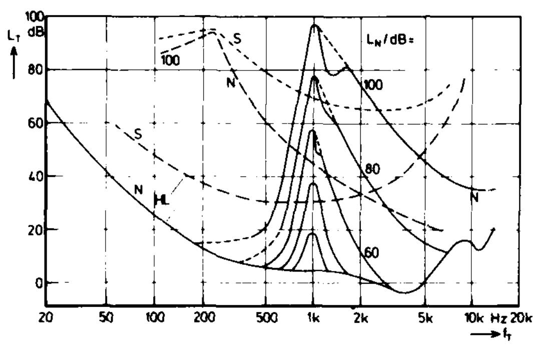

Fig.8: Masked threshold for sinus tones (L_{T}), masked by narrow-band noise (L_N) for normal-hearing persons (N) at 1 kHz (- from Zwicker 1967); for persons with slight hearing loss at 250 Hz (S -·-, N - -, from Rittmanic 1962); threshold of audibility (L_{HL}) for normal-hearing (N) and persons with hearing loss (S).

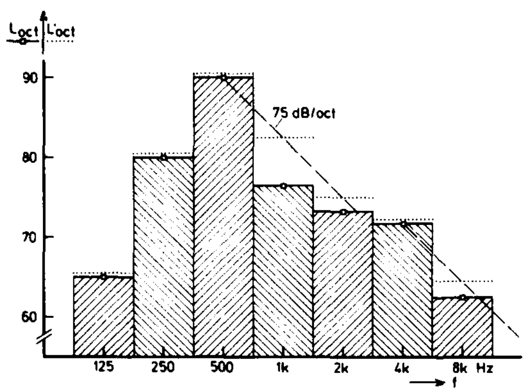

Fig.9: Masked threshold for alarm signals.The octave sound pressure level (L_{oct}) is measured. Masked threshold in octaves (L'_{oct}) is greater than or equal to the measured octave sound pressure level ($L_{oct} \leq L'_{oct}$). The masked threshold of the higher octaves is derived from the octave sound pressure level of the lower octaves, whereby the level of the masked threshold decreases by 7.5 dB per octave (- - -).

An analysis of acoustic and optic transmission of information (Burkhardt & Küssner 1977) at 4 different job locations in underground mines resulted in different frequencies of used acoustic and optic signals as well as the verbal communication, depending on the activity and the working procedure:

	acoustic signals	optic signals	verbal communication
work-process	0.5 - 90 %	0 - 60 %	0.5 - 2.5 %
informal	3.0 - 16 %	1 - 17 %	5.5 - 41 %

In an experiment (Bock et al. 1982), students classified 20 alarm signals, e. g. , horns and sirens on different scales (continuous scale: not dangerous (1) to dangerous (7), see Figure 10).

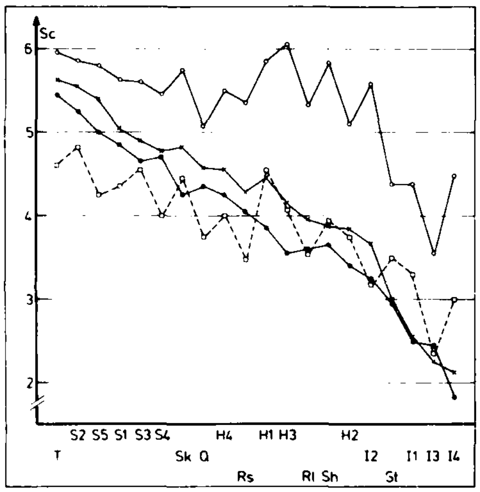

Fig. 10: Averages for the scale (7 - 1) 'dangerous' (•-•), 'threatening' (x-x), 'unpleasant' (o-o), 'induces escape behavior' (□ -- □) for 20 on-the-job alarm signals. The sequence of the signals is the result of the average of the scale 'threatening' and 'dangerous'. (comment see Figure 11, 12) (from Bock et al. 1982).

Furthermore, the relationship between 20 alarm signals and 24 occupational danger situations (e. g., toxic substances, fire, accident) were examined. The subjects matched the signal they heard to the corresponding danger situation on a compatibility scale (compatible (6) to not compatible (1)). Based on shared compatibility, six to seven signal groups can be formed (Lazarus & Höge 1982) Figures 11, 12). Signals with increasing and decreasing frequencies are best suited as alarm signals. In DIN 33409, a signal with decreasing frequency to be used as an emergency signal for working areas (evacuation signal) is recommended by Lazarus (1980).

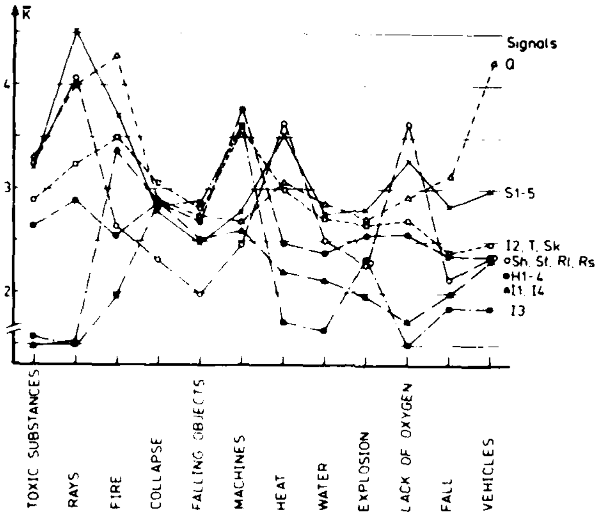

Fig. 11

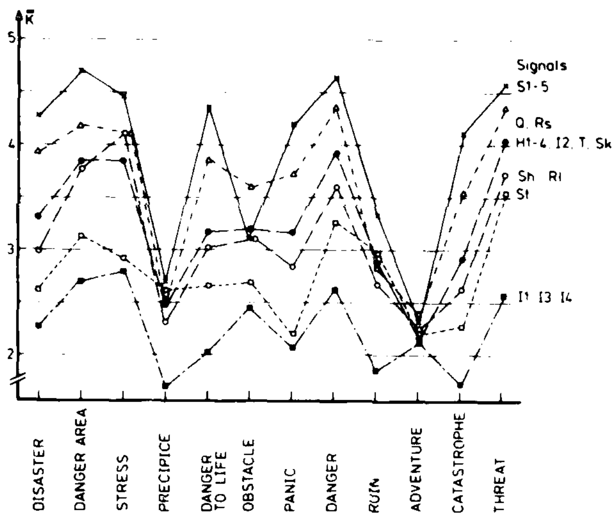

Fig. 12

Fig. 11, 12: Averages for the compatibility (6 - 1) (k) for 6 - 7 signal groups from 20 alarm signals for 12 general danger situations (Fig.12) and 12 specific danger situations (Fig.11); (from Lazarus & Höge 1983). S 1 - S 5 = sirens with varying frequency .5 - 1.2 kHz; Q = quarter interval; Rs, Re = pulsed square wave; Sh, St = sinus tones; I1 - I4 = periodic impulses (e.g., bell); H 1 - H 4 = horns, Sk = siren with a constant frequency, T = typhon-signal

DISORDERS OF VOICE CAUSED BY LOUD SPEAKING.

Periodic or continuous strain on the voice can lead to organic disorders of the larynx. The strain occurs because of loud speaking and is especially prevalent in high noise activities and in the teaching profession. Habermann (1980) quoted a statistic in which educators with disorders of voice account for 40 - 50 % of all people with voice disorders.

In laboratory experiments, Klingholz et al. 1976, 1978 gives the following relationships: The percent of healthy-voiced persons showing pathological deviations when speaking in high noise levels increases as the noise level increases (Figure 13). Klingholz performed an experiment with kindergarten teachers and workers who work in noise (L_{NA} = 60 - 120 dB). Fifty percent of the teachers had disorders of larynx. By workers with speech intensive-activities, functionally caused voice problems occur 3 times more often than by workers who perform no speech-intensive activities.

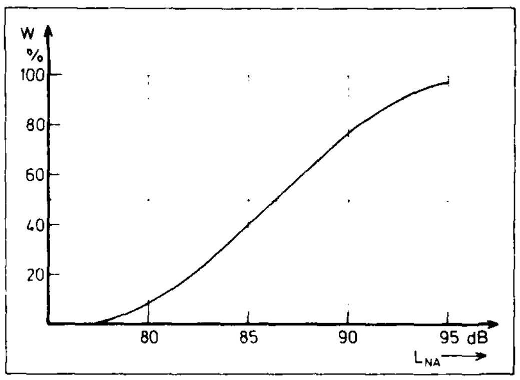

Fig.13: Percent of the people (W), who show pathological deviations in voice production at noise level (L_{NA}) (from Klingholz et al. 1978).

ANNOYANCE IN VERBAL COMMUNICATION

In an experiment on disturbance caused by office noise (Nemecek & Turrian 1978), 228 persons in 57 offices were interviewed. The equivalent continuous sound level was between L_{Am} = 43 - 63 dB. 35 - 44 % felt disturbed in verbal communication relatively often to very often, 29 - 36 % once in a while, and 27 - 29 % rarely or never. The relationship

between disturbance of verbal communication and the noise level is only moderate.

In connection with studies on the annoyance caused by environmental noise (traffic, aircraft, railway noise), the question of the disturbance of communication (conversation, radio, TV) is also raised. Kastka (1981) found 3 factors with the aid of a factor analysis on annoyance reactions caused by traffic noise. One factor represents the disturbance of communication. The evaluation of several studies (DFG-study 1974, Grandjean 1976, Nemecek & Wehrli 1979, Finke et al. 1980) is given in Figure 14.

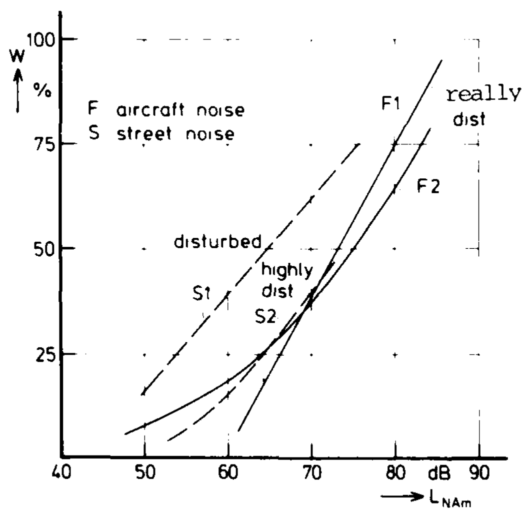

Fig.14: Percent of the people (W), who feel disturbed in their verbal communication by traffic noise. The number of persons is given who have a score on the rating scale (Scale 1 - 5, 1 - 2, 1 - 10) which is higher than a pre-established cutoff :
F1: air noise (DFG-study 1974, Sc: 1 - 5) > 3, 6°°-22°°;
F2: air noise (Grandjean 1977, Sc: 1 - 2) = 2, 6°° - 22°°; S1: street-traffic noise (Finke et al. 1980, Sc: 1 - 5) ≥ 3; 18°°-22°°;
S2: street-traffic noise (Nemecek & Wehrli 1979, Sc: 1 - 10) ≥ 8.

Using the same equivalent continuous sound level, street noise exceeds the critical noise level for verbal communication more often than aircraft noise. Because of this, disturbance of communication is probably higher by street noise. Kastka (1981) also shows that, using the same daytime equivalent continuous sound level L_{NAm} = 74 dB, the continuous noise of the motorway (Autobahn) is more disturbing for communication than noise caused by city traffic. For communication, railway and traffic noise are nearly equally disturbing (Knall & Schümer 1981).

In a laboratory experiment (Lazarus-Mainka et al. 1983),

the question of experienced annoyance during verbal communication was raised. Two subjects carried on a conversation at noise levels L_{AN} = 74 - 92 dB. The speaker and hearer differ in the type of annoyance: The speaker feels more strongly annoyed and handicapped; the hearer feels more strongly confused, distracted and strained to excess.

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COMMENTS ON RECENT SOVIET LITERATURE ON NOISE AND SPEECH INTELLIGIBILITY

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It is virtually impossible for a researcher in the West to access all Soviet literature in any one scientific field or sub-field. As is well known, Soviet specialists in the area of documentation and library scientist have not developed any system of indexing materials apart from the monthly tables of contents and annual indexes appearing in most professional publications. Accessing literature thus requires the researcher to search virtually every issues of every periodical in published in the given field. Western sources have attempted to make up for the Soviet deficiency by listing and summarizing key Soviet materials in basic discipline journals and in the various international science, psychology, social science, and environmental indices. A review of these indices for the last five years, however, yields only one major article on noise and speech intelligibility, and only a few on one of the Soviets pioneering fields of interest, noise and noise sickness. Clearly, the selection of articles to be included in such indices depends on the preference orientation of the indexer and his access to Soviet periodicals.

Second, there is little translated Soviet research in this area in the English language. A notable exception is the translation effort of the Joint Publication Research Service of the US Federal Government. Happily, this service is accompanied by an index, which if not totally systematic, at least enables the researcher to access the appropriate sources. Here again, however, one finds the selection of translations dependent upon the orientation of the compiler, in this case, the various departments of the US Federal Government. A search of translated materials in this Service over the last five years found once more, only one article specifically dealing with noise and speech intelligibility, although almost forty dealing with the effects of noise on performance. The bulk of the translated materials concern engineering and technological research into the reduction of noise interference in transmissions systems, particularly in a military context, or evaluations of noise on performance in space capsules and space

technology.

Clearly there is a need for a more systematic approach to accessing Soviet research in all areas, and particularly in the areas of noise and vibrations. Like other countries, the USSR has not spent as much effort in the area of the effects of noise on human beings as it has on the larger priorities of, for example, nuclear energy research, but our sojourn in the USSR in 1980 and subsequent follow-up provided convincing evidence that the Soviets are carrying on significant research on noise, research which should be better communicated to the international scientific community. We also discovered that Soviet audiologists are eager to report their research. However, the laws of export say that no one may export a book from the USSR which was published over three years prior to the proposed exportation date without obtaining a permit from the Ministry of Culture and the payment of 100% export duty if the permit is given. The law effectively inhibits Soviet scientists from mailing any materials abroad to interested colleagues except the most recent. Given the small editions of scientific books, seldom over 3000 and more often in the 1500 range, it is improbable a Western scientist could obtain a copy of a book, even if he knew about it, by ordering it either from authorized Soviet bookstores abroad or directly from the publisher. In all likelihood, the volume would have been sold out within a few days of its appearance in the appropriate domestic bookstores. Probably the best Western collection of Soviet materials in Russian relating to the field of noise and human health and in the general area of health and sanitation is the Institute of Health and Sanitation in Helsinki, Finland. The Western researcher is thus faced with two difficult choices. He must have a knowledge of Russian, and either spend time in the principal Soviet research centers in Moscow, Leningrad, or Kiev, or contact the Institute of Health and Sanitation in Helsinki, or he must rely on the unsystemmatic attempts of Western indexing systems to acquaint him with Soviet work in his field.

What follows is only the briefest summary of what we learned in the Soviet Union and a proposal on how to alleviate this unproductive situation.

Major work on the effects of noise, particularly on human performance is confined mainly to Moscow and Leningrad. Of the two cities, Leningrad has been the pioneer in research on noise and noise sickness. During the 1960s, four scientists at the Leningrad Medical Institute of Hygiene and Sanitation under the USSR Ministry of Health undertook research on noise sickness: Ye. Ts. Andreyeva-Galinina, S. V. Alekseyev, A. V. Kadyskin, and G. A. Suvorov. Their findings were published in a book entitled NOISE AND NOISE SICKNESS (Leningrad, 1972), which has since

become the Russian standard on the subject. The book was translated into English by NASA in July 1973. The most significant data concern the effect of noise, especially industrial noise, on the functional state of the central nervous system. It is concluded that both reactivity and lability of the cortex and subcortical structures are reduced, evidently in proportion to the noise effect. The degree of these effects, according to the authors, is determined by the force of the noise. The authors establish that pulsed and steady state noise affect tissue respiration of the cerebral cortex, pulsed noise having an especially unfavorable, irritating effect.

Galinina subsequently died and Alekseyev took over as Director of the Institute. Together, he, Kadyskin and Suvorov published another book entitled SOME DATA ON NOISE SICKNESS AND ITS PREVENTION (Leningrad, 1972). In 1973, the same three together with N. I. Karpov presented a paper, "On the Question of the Biological Action of Infra-Sound" to the All-Russian Conference on Noise and Noise Sickness, Questions of Prevention." And in 1975, Suvorov and Likhnistkii, a research physician with the Soviet Navy, published IMPULSE NOISE AND ITS INFLUENCE ON THE HUMAN BODY (Leningrad, 1975). The book is a combination of acoustical engineering and research work, which evaluates impulse and intermittant noise on the basis of their information rather than energy content. According to N. Goldman, a researcher at the Canadian Centre for Occupational Health and Safety, it provides the Western scientist with a good example of the East European approach to questions such as impulse noise control, noise fatigue, and the auditory and non-auditory effects of impulse noise.

When we visited the Institute in November 1980, Director Alekseyev asked his research heads to inform us of the present status of noise sickness research there. While some data was presented indicating that the Institute had firmly established that certain kinds of noise caused illness, our meeting was too superficial to go into much detail. The impression gathered was that research in this area had somewhat fallen off. Our invitation through the USSR Ministry of Health and the USSR Academy of Sciences to bring a Soviet specialist to this conference to make a presentation on Soviet research on noise sickness, went unanswered.

Since 1975, other centers have come to the fore with their research into the effects of noise and vibration on human performance. Among the published work are the following:

The first in chronological order is an article by Prof. V. Ye. Oistapkovich and Candidate of Medical Science I. M. Korol' of the Scientific Research Institute of Labor Hygiene

and Occupational Diseases, USSR Academy of Medical Sciences, Moscow, entitled "Analysis of Cochleovestibular Correlations Accompanying the Effects of Noise and Vibration" (Vestnik otorinolgaringologii, No. 2 (1978), pp. 17-20). The authors base their findings on audiometric and vestibulometric analyses of an unspecified number of workers from 20-50 years old subjected to the effects of noise and vibration. The authors find that the relationships for the group subjected to noise and vibration and noise vary. However, clinical observations established dysrhythmia and variable-amplitude nystagmus supporting the hypothesis that these phemonema were caused by vibration and noise.

In 1979, Ye. P. Samoiliuk and V. V. Safonov published a book entitled THE STRUGGLE AGAINST NOISE AND VIBRATIONS IN CONSTRUCTION AND AT ENTERPRISES OF THE CONSTRUCTION INDUSTRY (Kiev, Budivel'nik Publishing House, 1979). The book contains reports on the work of Ukrainian research and zplanning organizations on the noise characteristics of machines, methods of noise reduction, and the effects of noise on performance. The book is designed as a handbook for engineering and technical personnel in the construction and planning industries.

A continuation of the Alekseyev- Suvorov line of research is P. I. Mel'nichenko's research on "The Effect of Pulsed Noise on Man" published in the Military Medical Journal, No. 12 (1980), pp. 44-46. The study's objective was to study the systemic reaction of healthy young adults to intensive pulsed noise. The frequency range of pulsed noise was 0-10 kHz. The subjects were exposed once to 5 to 50 pulses, each of which lasted up to 10 ms, with 10 s intervals between them. The effect of the pulsed noise was measured on the basis of tonal audiomery (air and bone conduction), heart and respiration rates and arterial pressure. A questionnaire was administered to test the subjects' subjective reactions. The study found that there was a significant relationship between the subjects' subjective state and the intnsity of the noise. A marked worsening of the subjective state was noted with very loud noise (165 dB and higher). The study further confimed that pulsed noise has an adverse effect on different functional systems of the human organism and recommend a "complex" approach to the study of the effects of pulsed noise. Particularly substantial disturbances occur with exposure to pulsed noise over 165 dB and the authors recommend this level as the guildeline for establishing permissible levels of pulsed noise.

A study by G. A. Manovtsev, V. A. Korsakov et al., entitled A STUDY OF MAN'S ADAPTIVE REACTIONS TO THE ACOUSTIC ENVIRONMENT IN AN ENCLOSURE (Cosmic Biology and Space Medicine, Vol 16, No. 2 (March-April, 1982), pp. 76-81) looks at the acceptability of noise levels in confined

spaces through the subjective evaluation of the acoustic environment by the subjects, and the examination of the subjects' cardiovascular functions. The study demonstrates an adaptive reaction to noise effects accompanied by an increase in tension in the cardiovascular system.

In another study published in the same journal in November-December 1982 (Vol. 16, No. 6), A. S. Rozenblum investigates "Short-term Acoustic Adaptation (STAA) as a Criterion of Resistance of the Auditory System to Noise". Experiments were carried out on 29 subjects with normal hearing and 46 patients with neurosensory hypoacusis, including 25 patients with occupational hypoacusis. The STAA magnitude was evaluated as the difference between the hearing threshold of the 20 ms signal paired with a preceding adapting signal or without it. The duration of the adapting signal was in the range of 20-1000 ms and its intensity was 40 dB above the hearing threshold. The signals were applied signals were applied at 50 ms intervals. The STAA value was 5-25 dB in 90% of the normal subjects. In the patients with occupational hypoacusis, hearing impairment increased as STAA declined. This relationship did not obtain with the patients with common neurosensory hypoacusis. The author recommends using STAA as a measure of man's hearing resistance to noise effects.

It will be noted that all the foregoing studies relate to the effects of noise on human performance. Only two references were found in the JPRS during the period 1975 to the present, pertaining specifically to the effects of noise on speech intelligibility. "The Effect of Auditory Fatigue on Speech Perception in the Presence of Intensive Low-Frequency Noise" by A. G. Antonov, B. V. Ovchinnikov and A.S. Permyakov (Military Medical Journal, No. 6 (1975), pp. 56-57) provides a summary report of a study of the influence of functional changes in the auditory system on clarity of speech in the presence of intensive low-frequency noise. 36 communication operators particpated in the study. They had normal hearing and were exposed during their work to low-frequency noise in excess of 110 dB with the maximum level of sonic energy in the frequency range of 20-160 Hz. The subjects ranged in age from 18-22 years of age. One group of 14 was exposed to noise continuously for 10 to 30 hours over a 2-day work period. A second group of 22 subjects was tested with a shorter exposure of 2 to 3 hours with 1 hour rest intervals. The authors measured the extent of hearing loss and compared it to the level of impairment of speech perception. They found that in cases of over 20% temporary hearing loss, the coefficient of verbal intelligibility drops significantly. A 30-40% hearing loss leads to great difficulty in verbal communication in the presence of low-frequency noise. In such cases, proper speech perception requires very intense attention, accompanied by requests to repeat words and sentences. The

authors suggest their results make it possible to set standards for acoustic conditions of work for preset levels of quality of communications in combat material.

In a second article by S. N. Losiakov and I. S. Nekrasov, the results of a study of noise immunity of speech messages in wideband radio telephone communication systems are discussed (Kiev, Izvestia vysshikh uchebnykh zavedenii: Radioielektronika (News of Higher Education: Radioeletronics), Vol. 245, No. 1 (January 1981), pp. 56-61.)

A final area in which Soviet researchers have been active which relates to the subject of noise and speech intelligibiity is research on deafness. Work is being done in the First Medical Institute of the USSR Ministry of Health in Leningrad, the Research Institute of Otorhinolaryngology and Speech Pathology of the USSR Academy of Sciences in Leningrad, and at the Institute of Defectology under the USSR Ministry of Education in Moscow. The First Medical Institute is engaged in diagnoses, rehabilitation and hearing aid fitting for children. Vibrotactile aids are used only for very young very deaf children as an aid for speech pathology. To test the effect of increasing the volume of the hearing aid on speech intelligibility, a group of 21 hearing impaired and profoundly deaf children were exposed over a period of forty months to three hours daily of hearing aid training. The study indicated a threshold of 90 dB beyond which there was no significant improvement in speech intelligibility. The study also indicated that increasing the volume of the hearing aid produced no noticeable further hearing impairment over the 40-month period.

At the Leningrad Research Institute of Otorhinolaryngology and Speech Pathology, A. S. Rosenblum and his colleagues are engaged in research in speech production in deaf children. We observed a training session for a pre-school child which incorporated aspects of the Yugoslav (Dr. Goborina) method. Rosenblum has compiled a very useful bibliography on THE PATHOLOGY OF SENSORINEURAL DEAFNESS, 1966-1973 (Leningrad, Meditsina Press, 1977), which contains Soviet as well as Western references. A co-authored study by Rosenblum, L. N. Petrova and V. K. Krishchenkov examines the "Application of Audiometric Tests for Evidence of the Influence of Stapedoplastics on the Inner Ear in Patients with Otosclerosis." In another co-authered study in the same volume, Rosenblum report on "A Comparative Evaluation of Several Methods of Clinical Masking for the Investigation of Thresholds of Air Conductivity" (QUESTIONS OF THE PHYSIOLOGY AND PATHOLOGY OF ACOUSTIC AND VESTIBULAR ANALIZERS, Vol. XXI, A (Moscow: RSFSR Ministry of Health, 1977.) Rosenblum's current research is the development of an acoustic apparatus to test hearing impairment.

The Faculty of Philology at Leningrad University is engaged in the development of speech intelligibility tests for the deaf. Dr. A. S. Stern, in particular, is engaged in research on a test which would evaluate speech perception and spoken language skills of the young deaf population. Her approach is to develop a comprehensive test which will measure all aspects of speech intelligibility and she was sceptical of the reliability of US tests which isolated the various factors and claimed to test only one aspect at a time.

The Institute of Defectology in Moscow is the principal center for research on education for handicapped children of all kinds, including the profoundly deaf. Research is carried on in such areas as the formation of spoken speech in deaf children, educational materials designed for the hearing impaired, the development of memory and thought in deaf children, and the evaluation of lip reading on speech production in the deaf. Of particular relevance to the area of speech intelligibility is M. I. Bel'tiukov's research in the INTERACTION OF ANALYSERS IN THE PERCEPTION AND ACQUISITION OF SPOKEN LANGUAGE (Moscow: Pedagogika Press, 1977). In a study of eight children, Bel'tiukov determined that a general process may be described both for the perception and acquisition of spoken language, and that these two processes are related inversely to one another. Namely, certain complex phonemes are easily perceived and recognized early in the language learning process. However, these same phonemes are among the last acquired as aspects of spoken speech. For example, in the 36 step process of speech acquisition proposed by Bel'tiukov, r', sh, zh, and sh' are among the last phonemes acquired, but among the first perceived.

The above review provides only one individual's glimpse of the kinds of research being undertaken in the Soviet Union today in the areas of the effects of noise on performance and speech intelligibility, and the relationship between speech intelligibility and deafness. As was stated at the outset, a systematic effort is required to make Soviet research in audiology known to the international scientific community. A proposal for a more orderly dissemination of the results of Soviet research in this area would include the designation of some university or research center in either Western Europe or North America as the respository of Soviet journals on the subject. Perhaps the Institute at Helsinki might be interested, since it already has a substantial collection. A scientist in the field with a knowledge of Russian would be designated to keep up with the literature, and from time to time would publish reviews of what he considred the most significant work. The scientist cannot be expected to do such work on his free time and would have to receive some compensation. It would

seem appropriate that the committee look into this question and develop recommendations as how best to institute a literature review system. It is also suggested that methods be investigated as to how the literature review might be communicated back to Soviet researchers to inform them of the reception of their work abroad.

GENERAL REVIEW OF PAPERS PUBLISHED IN CZECH, SLOVAK AND POLISH LANGUAGES SINCE 1978

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INTRODUCTION

The influence of noise on speech communication has not been investigated in Czechoslovakia or Poland on as large a scale as has the influence of noise on health, hearing, and performance of those who are exposed to noise. Therefore, the number of publications on noise and communication has been very limited. According to unofficial information obtained from the Polish Academy of Sciences, no work has been published in Poland on this topic since 1977.

According to information from the Czechoslovak Academy of Science, the investigation of speech intelligibility in noise has been concentrated thus far at the Research Institute of Sound and Picture - VUZORT, Plzenska 66, Prague 5. Detailed descriptions of the methods and results of these investigations have been regularly published in the internal Research Reports of the Institute. Dr. Ivo Januška, who is conducting this research at VUZORT will present a paper on the topic "Influence of the mutual position of speech and noise sources on speech intelligibility in noise" at the 11th International Congress on Acoustics

in Paris, July 1983. In the following report, research conducted at VUZORT is briefly summarized.

VUZORT has conducted research on the influence of noise on speech since the sixties. The research topics were as follows: intelligibility of Czech speech masked by white noise, statistical distribution of speech levels, loudness of speech, and influence of room acoustics and background noise on speech perception. The most recent study was concerned with the combined effect on intelligibility of reverberation and noise coming to the listener from various directions.

Intelligibility of Czech syllables was measured in three reverberant conditions (T = 0, 0.4 and 2 s) for noise arriving to the listener from the front, left side, back, and above. White noise and octave band of noise with levels varying between -20 and +20 dB relative to the signal level were used. Speech at levels of 60 or 70-dB SPL was presented to the listener always from the front. A representative sample of values obtained is shown in Table I. Mean scores were obtained

Table I. Mean scores of correctly identified Czech syllables (in percent) for signal-to-noise ratio equal to 1. White noise was presented to the listener from various directions (from the front, behind, left side, or above). The speech was coming always from the front. Rooms with three reverberation times (anechoic room, and T = 0.4 and 2.0 s) were used.

	Direction of the noise source			
T in s	Front	Side	Behind	Above
Anech. Rm	40	81	82	77
0.4	39	61	67	54
2.0	24	46	46	

when both speech and noise levels were equal to 70 dB. The correlation between larger reverberation, and lower scores can be seen. The impor-

tance of relative positions of the signal and noise sources observed in the free field has been retained in the reverberant field. When the positions of the speech and noise sources coincide, the scores have the lowest values.

Wide-band white noise always reduced scores more than anv of the octave-band noises. The effect of reverberation for band noises was similar to wide-band noise. However, in the case of band noises, the best scores were obtained when the noise source was above the head and not in the rear as was the case for the wide-band white noise.

The effect of octave-band noise was dependent on the center frequency of the band. The order of octave-band noises from most detrimental to the least detrimental was found to be 2.0, 1.0, 4.0, 0.5, 8.0, 0.25, and 0.125 kHz. The relatively large effect on intelligibility of noise at 8.0 kHz was surprising. Januska attributed this to greater annoyance of high frequency noises as compared to annoyance of middle and low frequency noises.

It is possible, and indeed probable, that the limited time available for exchange of information prevented us to collect more data on publications on noise and communication which have appeared in Slavic languages. It is our feeling that additional studies have been conducted which have not appeared yet in formal publications. Those who would like to obtain updated information in the future should contact the Czechoslovak Academy of Science, Acoustical Commission, Provaznicka 8, 110 00 Prague 1 - Stare Mesto, Czechoslovakia, attn. Prof. Felix Kolmer, Dr. Sc. We have not as yet identified anyone in Poland who is currently interested in research related to speech perception in noise.

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STANDARDIZED METHODS FOR MEASURING SPEECH LEVELS

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Currently no standard method of determining speech levels exists. However, several systems do exist which are used for that purpose. Among the various instruments currently used for measuring speech levels are the VU meter, the graphic level recorder, the sound level meter, the sound spectogram and the integrating sound level meter. Although some standards have existed for some of the instruments, such as the VU meter and the sound level meter, no technique has been standardized for their use in measuring speech levels.

The difficulty in measuring speech is mainly due to its wide dynamic range which is at least 30 dB. In standards which use speech level such as the articulation index calculation standard (ANSI S3.5-1969), reference is made to the "long term RMS level". It is very difficult to measure this with an "average reading" on a sound level meter, or a VU meter, because a sample of at least ten seconds is necessary for stable readings. Even a graphic level recorder presents a

problem because of the large dynamic range involved and the difficulty in determining the average level as depicted in Figure 1.

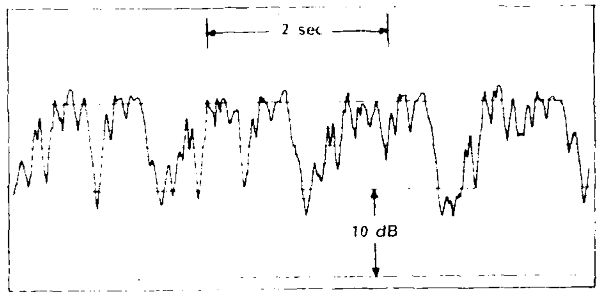


FIGURE 1. TIME PATTERN OF SPEECH ("FAST METER")

Some improvements may be obtained by slowing the writing speed to equivalent of "slow" sound level meter as shown in Figure 2, but the variation is still 6 dB. The sound spectogram is another technique used to measure speech, however, it only provides the temporal and spectral details of speech rather than providing an overall measure of vocal output. One metric which purports to measure speech is L_{eq}, obtained using an integrating sound level meter or computer. This measure shows some promise, however no standard techniques are currently available for its use.

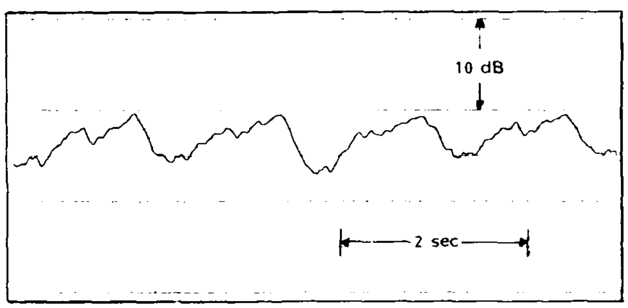


FIGURE 2. TIME PATTERN OF SPEECH ("SLOW METER")

DIFFICULTIES AND PROBLEMS

Speech comes in many forms, including continuous discourse, word lists, sentence lists with long pauses between sentences, and causal conversation. All of these forms encompass various amounts of pauses. Naturally, the greater the pause the more the error in determining the measure of speech. Another problem has to do with the amount of background noise in which the speech is embedded. Many times speech is used in relatively noisy situations and it becomes difficult to determine the long-term RMS level of the speech without the contamination of the background noise.

Many of the measures mentioned above are adequate for setting levels in an experiment. The VU meter on a tape recorder although not standardized may serve the purpose of setting a level on a carrier phrase associated with a word list. The speech from a different word list could then be reset at the same level. A sound level meter may provide a way of noting a 10 dB increase in speech level. However, when comparing levels between different experiments or between different labs these measures are not sufficiently repeatable.

Ideally, the standardized measures should be simple and be minimally affected by background noise, or pauses. Some simple approaches using sound level meters have been suggested in some standards involving speech intelligibility.

Table I summarizes such techniques. Basically both techniques measure the average of speech peaks on a sound level meter set on the "slow" scale. One uses C-weighting and the other A-weighting, but the net result should be the

same since the difference in normal speech level between A and C-levels is 3 dB which is the number specified in Table I necessary to correct the C-weighted result to the long term RMS.

TABLE I. SPEECH MEASURES USED IN STANDARDS

STANDARD	ORGANIZATION	DESIGNATION	DESCRIPTION
Methods for Calculation of the Articulation Index (ANSI S3.5-1969)	American National Standards Institute	ANSI [illegible]	Long term RMS taken as 3 dB less than average of speech peaks on sound level meter slow (C-scale)
Recommended methods for measuring the intelligibility of speech ([illegible])	International Standards Organization	Draft	Long term RMS taken as the average of speech peaks on sound level meter slow (A-scale)

COMPARISON OF MEASURES

Recently Steeneken and Houtgast (1978) have explored the relationships between various measures. The comparison was done to select "preferred" measures based on repeatability, influence of pauses, background noise, and relation to intelligibility. The tests used continuous discourse and test words embedded in a carrier sentence of two to three words. The A-weighted measures covered a smaller range than unweighted measures when adjusted for equal intelligibility. The peak measures were less affected by pauses and background noise than the others. All measures except peak reading measures using the sound level meter, or graphic level recorder, were quite reproducible with estimated variations less than 1 dB. An indication of some of the preferred measures are shown in the left hand portion of Figure 3.

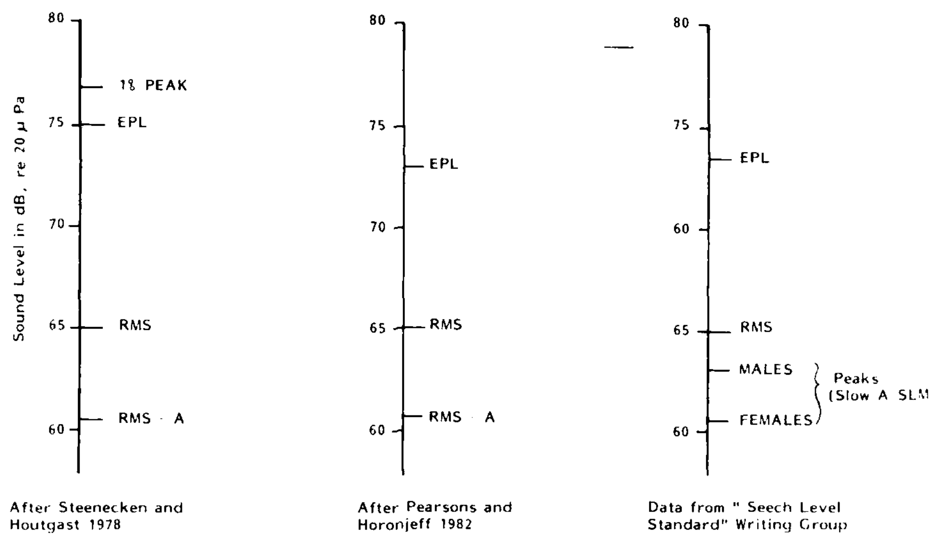


FIGURE 3. COMPARISON OF VARIOUS MEASURES FOR CONTINUOUS SPEECH

The figure also indicates relations between the various measures assuming that the RMS measure is 65 dB. Note that the Equivalent Peak Level (EPL) is about 10 dB higher than the RMS value. Other tests shown on the figure indicate a similar difference, but with a slightly lower value of 8 or 8.5 dB. Details of the EPL measure will be discussed later.

Difference between RMS and A-weighted measures averaged about 4 dB. The figure also indicates a difference between RMS and one of the approximations outlined in Table I. The approximation is about 2.5 dB below the calculated RMS value for a male talker, and 4.5 dB for a female talker using a variety of tests ranging from continuous discourse and word lists to nonsense syllables. The data on which these dif-

ferences are based also indicate a larger spread for the female voice level.

Further comparisons between A and C-weightings are shown in Figure 4 (Pearsons Bennett & Fidell, 1977) in which data for 100 subjects taken at local efforts of causal to shout are presented. Note that as vocal effort increases the difference between A and C is reduced. For shouting levels, there is no difference between A and C-weighted levels.

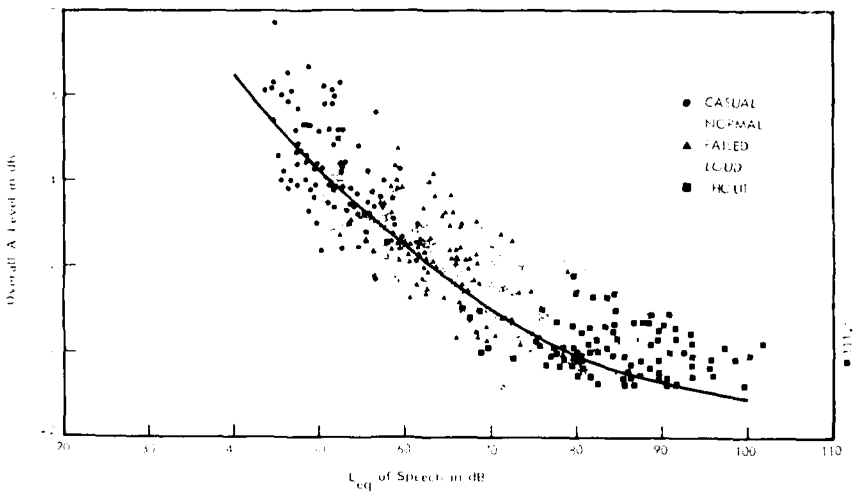


FIGURE 4. DIFFERENCES BETWEEN OVERALL AND A-WEIGHTED SOUND PRESSURE LEVELS OF SPEECH

As mentioned above, speech normally is measured for periods of 10 seconds to provide stable readings. However, some interest exists in determining the extent that people raise their voices during short term events such as truck passbys, or aircraft flyovers. Clearly, the 10 second samples would be too long for such measures. Therefore, speech measurements averaged over 2 seconds were tried. Although not as stable as the results of the 10 second samples, these

speech measures did indicate that people do raise their voices during short duration events. Figure 5 shows the speech levels occurring during the reading aloud of a newspaper article. The subjects wore ear phones and were presented with sounds as indicated in the lower part of Figure 5. Notice that the subjects did indeed raise their voices as the background noise grew in amplitude and lowered their voices as the background noise subsided.

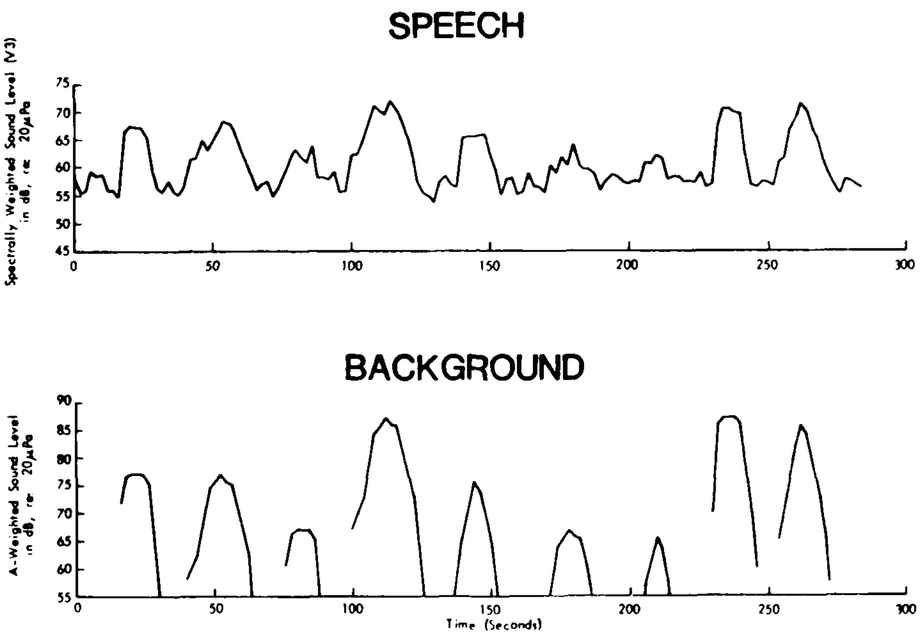


FIGURE 5. EFFECT OF BACKGROUND NOISE ON SPEECH

A summary of all results for all subjects and backgrounds shown in Figure 6 indicates that the voice level measured over a 2 second period increases by about 3.6 dB for each increase of 10 dB in background level.

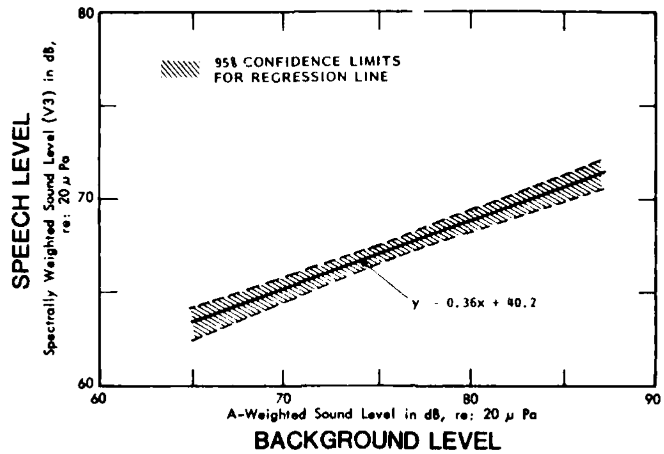


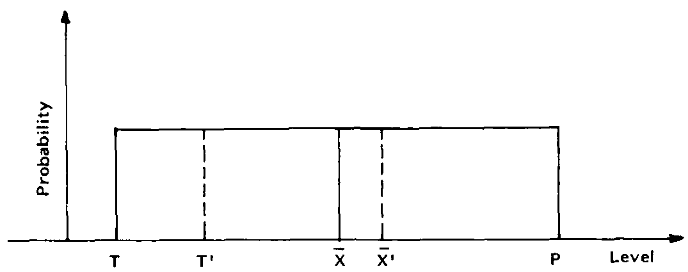
FIGURE 6. OBSERVED RELATIONSHIP BETWEEN SPEECH LEVELS AND BACKGROUND NOISE

A SUGGESTED STANDARD METHOD

Because of the many methods currently used to measure speech levels, a working group in the United States has set forth to develop a standard method. The group is currently considering the EPL and a long term RMS method. Although the RMS or Leq measures may be familiar, the EPL may not be as familiar.

The EPL was developed by Brady (1968) to provide a stable measure with minimum effects of pauses and background noise. One way to eliminate the effects of pauses is to set a threshold such that only levels above the threshold are considered. Unfortunately, speech is of such a large dynamic range that the resulting speech level depends on the threshold level selected. Brady noted that the distribution of speech level is log-uniform. That is, the percentage of levels 10 dB below the peak is the same as the percentage of levels

found 20 and 30 dB below the peak. As indicated in Figure 7, for an ideal situation the peak may be determined by measuring the average above some arbitrary threshold, doubling it and adding the threshold to the result. Note that if another threshold were selected, the resulting peak level remains the same. Thus as long as the distribution is uniform any threshold may be selected. If an RMS measure of pressure, instead of the average of intensity, was used, then the amount added to attain the peak is different, but nonetheless determinable.



$$P = T + 2\,(\bar{X} - T)$$

FIGURE 7. PEAK ESTIMATION FOR UNIFORM DISTRIBUTION

Figure 8 shows the result for such a measure. The measure using the average intensity is also shown indicating that if the average level is 10 dB above threshold, then the peak or EPL is 20 dB above the threshold. However, if the RMS of the pressure is determined, instead of average intensity (P^2), then for a true log-uniform distribution 15.7 dB is added to the threshold. Since some deviation from a true log-uniform distribution exists in speech samples at levels close to the peak, then an "empirical" three segment relation is used as indicated by the upper curve in Figure 8. Using this relation,

the amount to be added to the threshold if an RMS pressure value were 10 dB above threshold would be 14.8 dB. Further details of the EPL calculation are given in the Appendix.

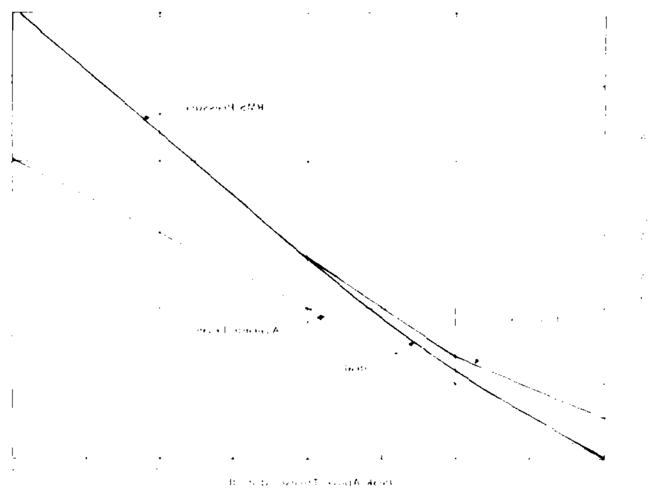


FIGURE 8. MEASURED AND PEAK VALUES OF SPEECH ASSUMING LOG-UNIFORM DISTRIBUTION

Long term RMS levels may also be used to provide a measure of speech. However, the sample must be at least 10 seconds long with no pauses and a noise level at least 35 dB below the speech peaks. If these qualifications are not met, then EPL should be used. The standard would also specify a simple sound level meter technique such as mentioned in Table I to provide an inexpensive method to determine speech levels. However, it is hoped that the EPL technique, if standardized, can be made available in a self-contained instrument to simplify and reduce the cost of EPL measurements.

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APPENDIX - STEPS FOR DETERMINING EQUIVALENT PEAK LEVEL

EPL may be determined by computer with an analog to digital converter capable of sampling at least 200 samples per second using the following steps:

1. Choose a threshold $\underline{T}$ between the noise level and the peaks of the speech. (A threshold 15 to 20 dB below the expected EPL works well; but the choice is not critical, since threshold independence of EPL typically holds over a threshold range of over 30 dB).
2. Measure the average pressure squared for only those pressures that exceed $\underline{T}$.
3. Convert this measurement to a decibel measure (10 Log P^2/P^2_{ref}).
4. Obtain D = rms minus $\underline{T}$. ($\underline{T}$ must also be expressed in decibels). Then compute a value Δ from D.
   a. $\Delta = (D-2.75)/0.4$, for $D < 6.75$.
   b. $\Delta = (D/0.675$, for $6.75 < D < 13.5$.
   c. $\Delta = (D+2.88)/0.819$, for $D > 13.5$.
5. EPL = $\underline{T}+\Delta$.

To facilitate the selection of a threshold in step 1, calculate EPL for three fixed thresholds 10 dB apart and choose one. For illustration, call the highest threshold zero the next minus 10 and the lowest minus 20. Under ideal conditions, these three values should be very close, but noise and/or speech output out of range (very high or very low) may invalidate one or more values. The following arbitrary algorithm is used to choose which EPL to select:

1. Look at EPL for the highest threshold (zero). If there were sufficient samples above T (at least 100 for a 200 Hz sampling rate) and if the EPL is at least 12 dB above T, choose this EPL. Otherwise go to step 2.
2. Look at EPL for T = -10 and repeat step 1. If EPL for I=-10 does not qualify do step 3.
3. Look at EPL for T = -20. If there were sufficient samples, print it regardless of value. If there were insufficient samples, print out a "null reading message."

The above algorithm attempts to select an EPL of between 12 and 22 dB above threshold. Noise rejection is incorporated by choosing the highest threshold satisfying the range condition.

EXPERIMENTAL VERIFICATION OF THE STI: A VALID BASIS FOR SETTING INDOOR NOISE LEVEL CRITERIA

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INTRODUCTION

Indoor speech intelligibility may be hindered by both interfering noise and room reverberation. Therefore, setting limits for tolerable indoor noise levels with respect to speech communication must be based on a concept which accounts for the combined effect of noise and reverberation. One such concept is that based on the STI (Speech Transmission Index). At the 1978-meeting in Freiburg, this approach was adopted for deriving indoor noise level criteria in relation to indoor speech intelligibility (Houtgast, 1978). Since that time, numerous experiments on speech intelligibility have been performed which allow a verification of the significance of the STI for a wide variety of conditions. It will be shown that these experimental data, which are summarized in this paper, emphasize the relevance of the STI-concept and, consequently, of the indoor noise level criteria as derived in the paper mentioned above.

RECAPITULATION OF THE STI-CONCEPT

The Speech Transmission Index reflects the influence of a speech transmission path on speech intelligibility. It is based on the Modulation

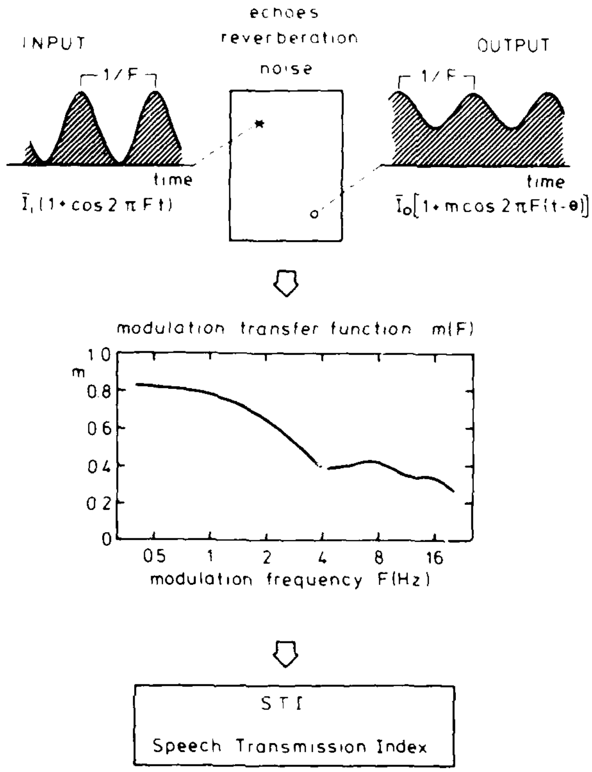

Fig. 1 - A speech transmission path can be characterized by the Modulation Transfer Function, quantifying the degree of preservation of the original intensity modulation as a function of modulation frequency. An additional parameter is the center frequency of the (octave-band filtered) noise carrier. These data are converted to the STI. (Houtgast et al., 1980.)

Transfer Function (MTF) which characterizes the detrimental effect of a sound transmission path on the temporal envelope of the original signal. A full treatment is presented in Houtgast, Steeneken and Plomp, 1980. The principle is illustrated in Fig. 1. For a test signal generated at a talker's position and received by a microphone at a listener's position, the quality of sound transmission can be characterized by the degree of preservation of the intensity modulations of the original signal. Para-

meters are (1) the modulation frequency F (typically from 0.5 up to 16 Hz) and (2) the frequency band of the noise carrier (typically an octave band, with center frequency from 125 Hz up to 8 kHz). Such a set of data on modulation transfer can be converted into the STI, reflecting the effect of that sound transmission path on speech intelligibility.

With special equipment, the MTF and the STI can be obtained from direct measurements. Also, in case a condition is specified physically (for instance, a given speech level, noise level and reverberation time), the MTF and the STI may be obtained from calculations. This latter approach was adopted in deriving the indoor noise level criteria given in Houtgast (1978).

It should be emphasized that the STI does not predict speech intelligibility as such since, obviously, this involves other aspects as well, like the properties of individual talkers and listeners and of the speech material. Hence, experimental verification of this concept implies that when these additional aspects are constant (same group of talkers and listeners, same type of speech material) we demand a unique relationship between STI and speech intelligibility, irrespective of the specific nature of the transmission channels involved. This is the essential aspect of the STI: it has been designed to account correctly for a large variety of possible disturbances, either in isolation or in combination (i.e., noise interference, reverberation and also distortion, bandpass limiting and others). In view of the perspective of this paper, we will concentrate on the experimental verification of the STI-concept mainly in case of noise interference and reverberation.

EXPERIMENTAL VERIFICATION OF THE STI-CONCEPT

In the '78-paper (Houtgast, 1978), the experimental verification of the STI was based on the set of data available at that time (Fig. 2),

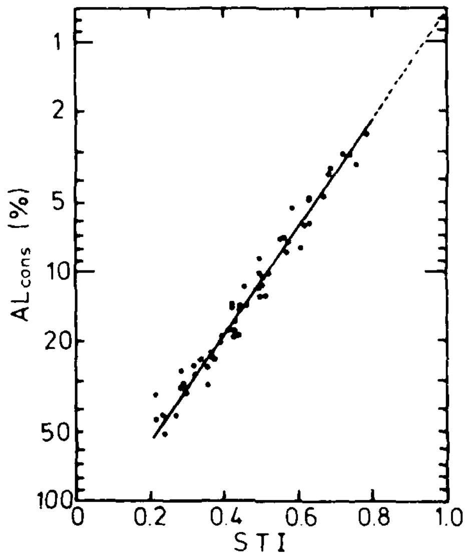

Fig. 2 - First experimental verification of the relation between the STI and an intelligibility score (Articulation Loss of Consonants) for a set of auditorium-like conditions. (Houtgast, 1978.)

which was limited in many respects. It concerned a combination of only two types of disturbances (noise and reverberation), only one type of noise spectrum was considered (speech-shaped), it concerned one specific measure of speech intelligibility (consonant score in case of well articulated word lists) and, finally, only one language was involved (Dutch). All these aspects have been considered in later experiments, the results of which will be briefly summarized.

Including other noise spectra (Fig. 3)

One example referring to other than speech-shaped noise is adopted from a study of Pols, 1981, investigating the intelligibility of consonants in conditions of noise and reverberation. The data in Fig. 3 refer to one type of reverberation (T = 0.5 sec), in combination with five

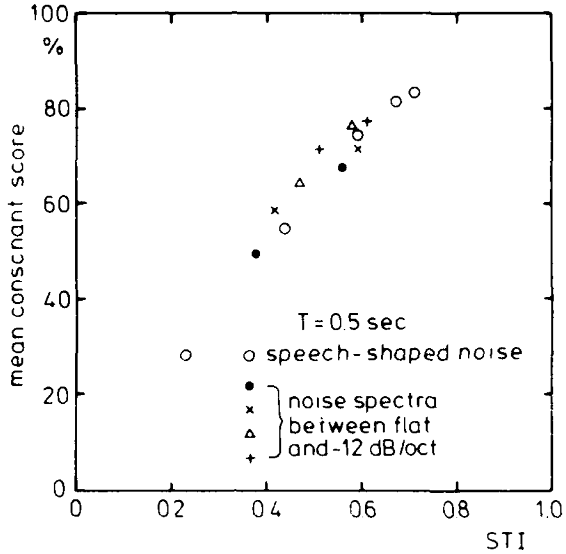

Fig. 3 - Illustration of the applicability of the STI in case of a combination of reverberation (T = 0.5 sec) and interfering noise with various spectral shapes (Pols, 1981).

types of noise spectra. For the speech-shaped noise five levels were considered, and for the other types of noise two levels. The results indicate that, essentially, the relation between the STI and intelligibility scores is not violated when considering other than speech-shaped noise.

Considering additional types of disturbances (Fig. 4)

In a study by Steeneken and Houtgast, 1980) the applicability of the STI-approach to a wide variety of speech communication channels was investigated. In total, 167 channels were considered including bandpass limiting, noise, peak-clipping, automatic gain control and reverberation. For these channels both STI measurements and intelligibility measurements with Phonetically Balanced word lists (PB-word scores) were performed.

Fig. 4 illustrates that a unique relationship between the STI and the

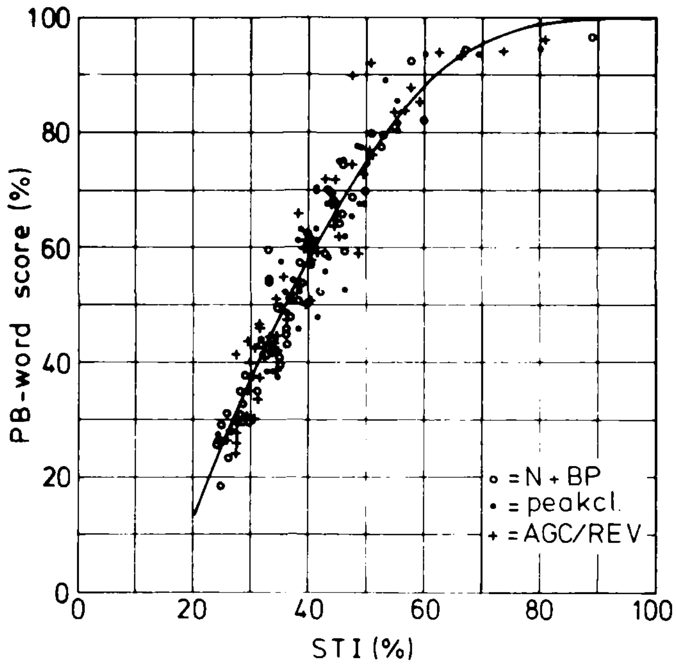

Fig. 4 - Relation between STI and PB-word score for conditions with noise (N), bandpass limiting (BP), peak clipping, automatic gain control and reverberation. (Steeneken and Houtgast, 1980.)

intelligibility score is maintained also for (combinations of) disturbances other than noise and reverberation.

Untrained subjects, outside the laboratory (Fig. 5)

In a series of field trials, the influence of traffic noise on speech intelligibility in classrooms was studied (Houtgast, 1981). In each classroom, the teacher read out a specially designed list of test words, and the pupils served as subjects. The pooled data are plotted as a function of the actual noise level during the individual test words.

Fig. 5 indicates that the results of this field study fit in with the STI-concept: the intelligibility scores agree well with the STI prediction

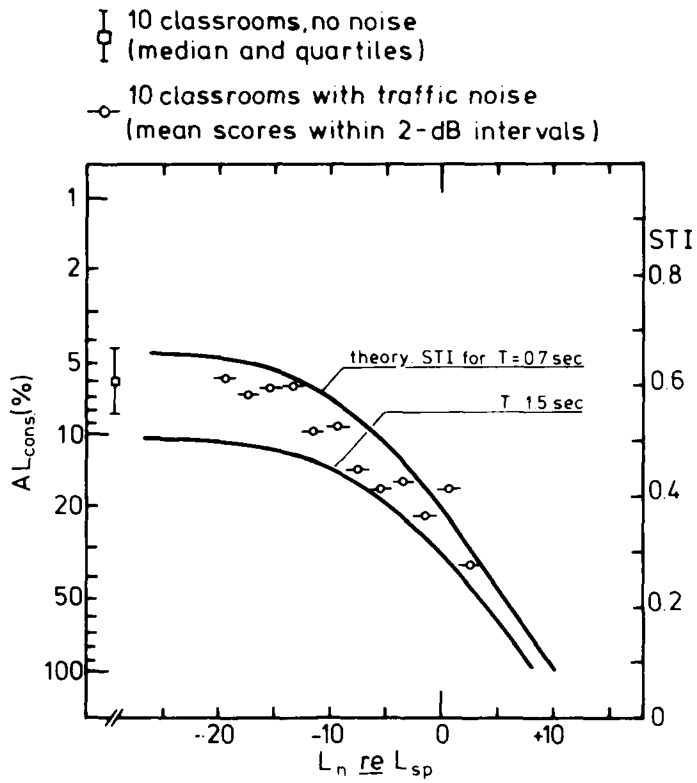

Fig. 5 - The Articulation Loss for consonants obtained in classrooms as a function of the noise level relative to the speech level (both in dB(A)). The two solid curves refer to the right-hand ordinate (STI), the relation between the two ordinates being dictated by Fig. 2. (Houtgast, 1981.)

for classrooms with reverberation times between, typically, 0.7 and 1.5 sec.

Sentence intelligibility and hearing-impaired subjects (Fig. 6)

A study of Plomp and Duquesnoy (1980) involve two new aspects in the experimental verification of the STI-concept (see also Plomp, Duquesnoy and Smoorenburg, this volume). First, the speech material consists of

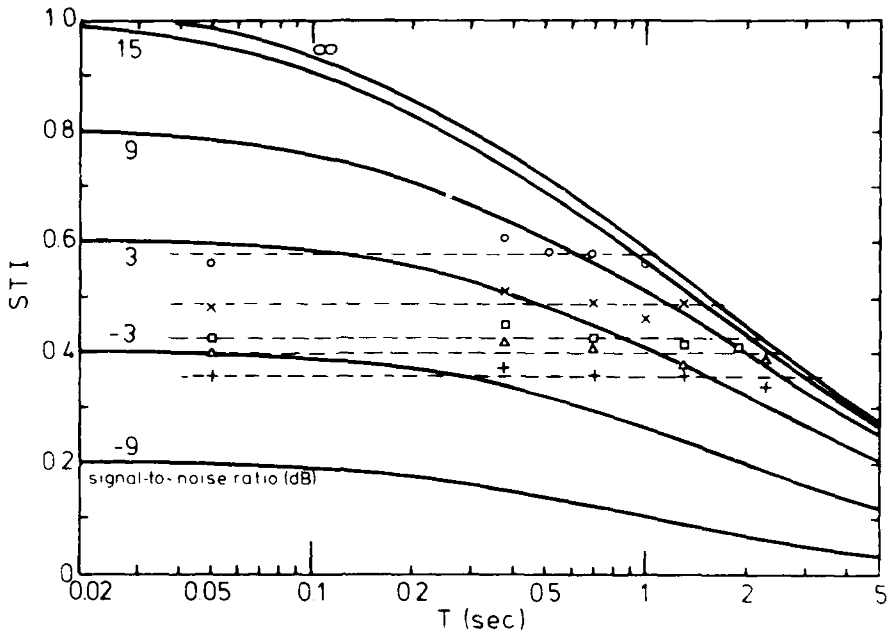

Fig. 6 - The solid curves represent the STI as a function of reverberation time, with S/N ratio as parameter. The data fitted by the horizontal lines give the average speech-reception threshold for a reference group (plus symbols) and four groups of hearing impaired subjects. (*Plomp and Duquesnoy*, 1980.)

simple sentences rather than test words and an adaptive procedure is applied to determine that speech-to-noise ratio at which 50% of the sentences are understood correctly 'the speech-reception threshold'. Second, the study involves groups of hearing-impaired subjects. Data on the effect of reverberation on the speech reception threshold (Fig. 6) indicate that within each group the condition of 50% sentence intelligibility corresponds, to a fair approximation, to a constant STI-value. Thus, within each group, the STI is uniquely related to the speech-reception threshold, irrespective of the relative amount of noise or reverberation.

These data suggest that the relevance of the STI extends to sentence intelligibility and to the hearing impaired (of the type investigated in

the study referred to).

Considering other languages (Fig. 7)

In a paper to be published by Houtgast (1983), data are reported on 16 (essentially auditorium-like) conditions, for which intelligibility measurements were performed in various countries. Also, these conditions were subjected to measurements according to the STI-approach. (A simplified method was applied which may serve as a screening method for auditoria and results in an index named RASTI: the Room Acoustics Speech Transmission Index.) One example of the experimental results is given in Fig. 7. The data along the ordinate include seven different languages and represent, essentially, the average rankorder of the 16 conditions as de-

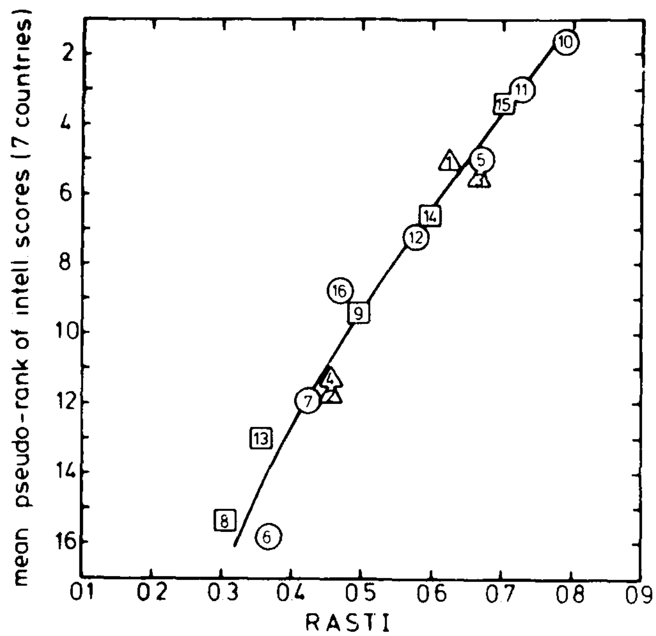

Fig. 7 - The relation between RASTI-values (this is a simplified version of the STI) and the mean data for seven languages as obtained for 16 auditorium-like conditions.
(Δ only noise, o only reverberation, □ noise and reverberation.)
From Houtgast, 1983.

rived from each individual language-specific articulation test. There is a good fit between these 'language-averaged' intelligibility data and the RASTI-values, with no discrepancy between the different categories of conditions involved.

These data suggest that the relevance of the STI-approach, which was originally tested for the Dutch language only, is not language specific.

CONCLUSIONS

The STI was developed to reflect the effect on speech intelligibility of a sound transmission path between a talker and a listener, irrespective of the nature of that transmission path. The experimental verification available at present proves the STI-concept being broadly valid: in addition to noise and reverberation it accounts for various other types of disturbances as well, the spectral shape of the interfering noise is not critical, it applies to various types of intelligibility scores of trained or untrained as well as hearing-impaired subjects and appears to hold for languages other than Dutch.

The significance of the indoor-noise level criterion as specified in Houtgast (1978), which was based on the STI calculation scheme, is strongly supported by the present data. Therefore, that criterion will be briefly recalled and generalized.

In a room one can specify a critical level. When setting limits for indoor noise, this critical level may serve as a lower limit: noise at lower levels does not effect speech intelligibility, irrespective of the characteristics of the individual talker or listener (including the hearing impaired), irrespective of the contents of the speech (e.g., redundancy) and irrespective of the talker-to-listener distance.

This critical level L_{cr} is defined by (1) the speech level to be ex-

public communication	private communication	L_{sp} (1 m front) dB(A)
raised	-	71
normal	-	65
-	raised	62
relaxed	-	59
-	normal	56
-	relaxed	50

pected, L_{sp} (1 m front) as specified above, (2) the room volume V in m^3 and (3) the reverberation time T (not outside the range of 0.5 to 5 sec):

$$L_{cr} = L_{sp} \text{ (1 m front)} - 10 \log V + 17 \log T + 8 \text{ dB.}$$

For interfering noise with a spectral shape similar to that of speech, L_{cr} applies to the A-weighted noise level. For noise with a diverging shape, L_{cr} applies to (SIL + 8), where SIL is the Speech-Interference Level: the arithmetic mean of the noise levels in the octave bands centered at 500, 1000, 2000 and 4000 Hz, respectively.

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EFFECTS OF NOISE AND REVERBERATION ON THE SPEECH-RECEPTION THRESHOLD OF HEARING-IMPAIRED LISTENERS

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INTRODUCTION

The difficulties for normal-hearing subjects in understanding speech in noisy and/or reverberant environments are found again, and much stronger, for hearing-impaired listeners. In recent years we carried out a series of investigations on the speech-reception threshold for sentences as a function of background-noise level. Some main results are presented below. As this research programme is still going on, this paper should be considered as a progress report. Space does not allow to refer to work by other investigators for which the reader should consult the review in Plomp (1978) and the other publications listed at the end of this paper.

HEARING LOSS FOR SPEECH IN NOISE AS A FUNCTION OF NOISE LEVEL

Hearing loss for speech is defined here as the speech-reception threshold (SRT) for sentences (50%-correct score) relative to the speech-reception threshold for young, normal-hearing subjects, measured for the same condition. SRT is, over a large range, almost exclusively determined by the speech-to-noise (S/N) ratio. Interpreting the absolute hearing threshold as having its origin in internal noise in the ear, the SRT for normal-hearing subjects can be represented (Plomp, 1978) by

$$SRT = 10 \log\left[10^{L_O/10} + 10^{(L_N - \Delta L_{SN})/10}\right], \qquad (1)$$

where L_O = SRT in quiet in dB(A);
L_N = sound level of the noise in dB(A);
ΔL_{SN} = number of decibels that SRT in noise is below L_N (= S/N ratio with opposite sign).

This equation holds both for monaural and binaural listening (directional effects excluded); the only difference is in the values of L_O and ΔL_{SN}.

The lower curve in Fig. 1 represents SRT for a listening condition representative of everyday situations, with L_O=16 dB(A) and ΔL_{SN}=8 dB. (Throughout this paper the speech level is the long-term average intensity of the test sentences.) The dashed curve represents the SPL of speech in face-to-face conversation at a distance of 1 m (van Heusden, Plomp and Pols, 1979). This curve demonstrates that people increase their voice

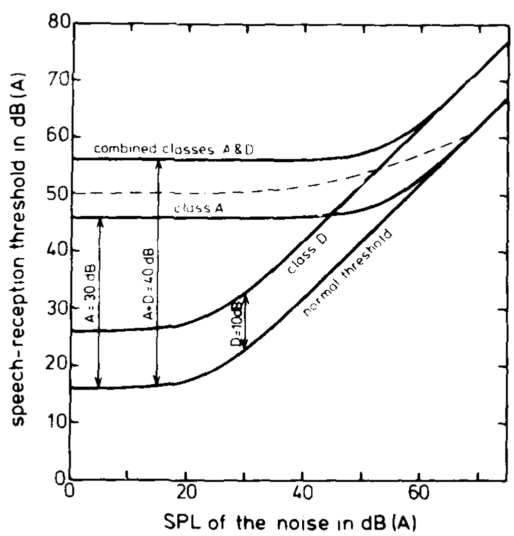

Fig. 1. Binaural speech-reception threshold for sentences, reproduced over a loud-speaker at a distance of 1 m in front of the listener, as a function of the level of diffuse noise with a spectrum which is the same as the long-term average spectrum of the sentences. The lower solid curve represents normal hearing (equation 1), the other ones hold for hearing losses for speech as indicated (equation 2). The dashed curve represents the average sound-pressure level for conversational speech.

level automatically when interfering noise is present.

The remaining three curves of Fig. 1 illustrate the effect of hearing loss on SRT. Any hearing loss for speech can be interpreted as a combination of two component parts belonging to different classes: class A, comparable to attenuation of all sounds entering the ear, and class D, comparable to distortion of these sounds. A hearing loss of class A means an equal shift of the lower curve of Fig. 1 along both axes (45°), corresponding to a hearing loss for speech in quiet of, say, A dB and no hearing loss for speech at high levels of the interfering noise. A hearing loss of class D can have its origin in a deterioration of the ear's frequency-analyzing power, a specific loss for the high frequencies, etc., requiring a higher S/N ratio both in quiet and in noise; this means that the threshold curve is shifted vertically over, say, D dB. In Fig. 1 SRT curves are plotted for a class-A loss of 30 dB, a class-D loss of 10 dB, and the combination of these two losses. They are given by the following extension of equation (1):

$$SRT = 10 \log\left[10^{(L_O+A+D)/10} + 10^{(L_N-\Delta L_{SN}+D)/10}\right], \qquad (2)$$

where A+D = hearing loss for speech in quiet in dB;
D = hearing loss for speech in noise in dB.

This formal distinction between class-A and class-D hearing losses should not be confused with the traditional, anatomically oriented, distinction between conductive and sensorineural hearing losses. For purely conductive losses D=0, for sensorineural losses the ratio D/(A+D) can vary to a considerable degree. Furthermore, equation (2) should be seen as a first-order approximation, with the underlying assumption that D is independent of noise level, which may not hold for particular (sloping) audiograms and in case of recruitment.

By comparing the two curves labeled class A and class D with the

dashed curve, the very different nature of the corresponding handicaps is apparent. The curve for A=30 dB represents a considerable loss at low levels, but above about 55 dB(A) hearing is almost normal. The curve for D=10 dB, however, represents a minor hearing loss at low noise levels, but means a substantial handicap above 55 dB(A). In the latter case conversational speech at a normal voice level will not be understood at noise levels beyond about 52 dB(A), whereas this limit is about 68 dB(A) for normal-hearing subjects. This illustrates that, in addition to the hearing loss in quiet, it is very important to know the hearing loss for speech in noise.

The model given by equation (2) can be extended easily to include the case of the hearing-impaired subject provided with a hearing aid. The aid's acoustic gain has to be subtracted from the attenuation loss A and its distortion effect in terms of S/N ratio has to be added to D. Since the hearing aid amplifies both the wanted speech signal and the interfering noise, it does not improve S/N ratio and, therefore, it is in most cases not effective at noise levels beyond about 55 dB(A) (see for experimental data Duquesnoy, 1982; Duquesnoy and Plomp, 1983).

In an extensive study, Duquesnoy (1982) found that equation (2) fits the measured data points quite satisfactorily, indicating that only two numbers, A and D, are sufficient to describe hearing loss for speech as a function of noise level. In earlier experiments (Plomp and Mimpen, 1979b) SRT was investigated as a function of age. Figure 2 represents the results for 140 male subjects, with age as the parameter. The 50%-correct thresholds were measured for carefully prepared sentence lists in an adaptive procedure (Plomp and Mimpen, 1979a) with the spectrum of the interfering noise made equal to the long-term average spectrum of the sentences. (This spectrum was chosen in order to obtain SRT values representative of the

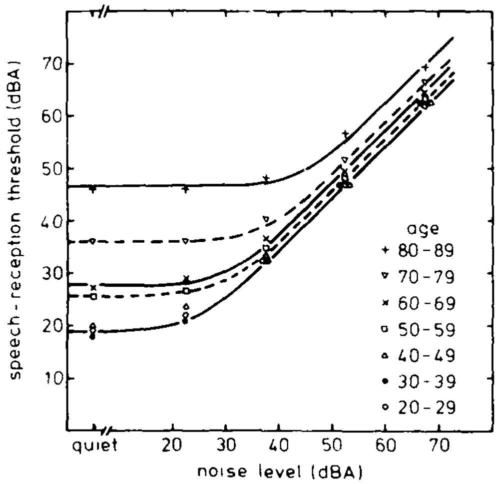

Fig. 2. Median values of the speech-reception threshold for sentences as a function of noise level for the individual ears of seven groups of 20 male subjects each. The curves represent the best-fitting curves according to equation (2) (Plomp and Mimpen, 1979b).

condition of many competing speakers, and was applied in all further experiments referred to in this paper.) The diagram shows that, whereas hearing loss for speech in quiet (=A+D) increases up to about 26 dB for the 80-89 year subgroup, hearing loss for speech at high noise levels (=D) increases up to about 7 dB. For this group and a group of 72 female subjects (age 60-96) the effect of age on the hearing loss for speech in noise is summarized in Fig. 3. We see that the percentage of people with D exceeding a certain value increases rapidly with age, demonstrating that hearing handicap in noise is primarily a problem of the aged.

One should not be misled by the fact that the values of D seen in Figs. 2 and 3 seem to be rather small. We should realize that the percentage of correctly understood sentences increases very rapidly with S/N ratio, 15% to 20% per dB. This means that a hearing loss for speech in noise of only 3 dB or more, which is shared by more than 40% at the age of 70 (Fig. 3),

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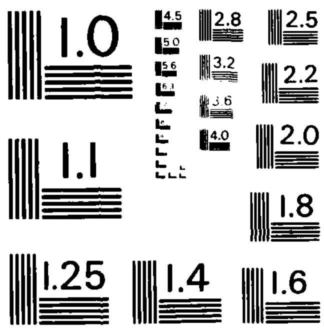

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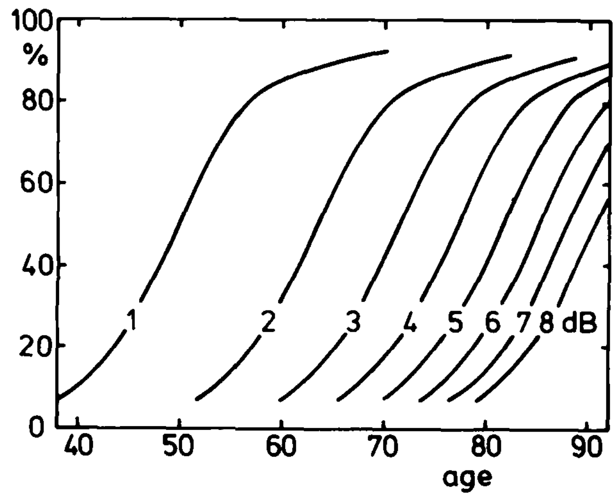

Fig. 3. Average percentage of population with a hearing loss for speech, D, exceeding 1, 2, 3, ..., 8 dB, respectively, as a function of age.

makes it almost impossible to follow a conversation at an S/N ratio just tolerable to normals.

In further experiments the effects of other parameters on the SRT in noise were explored: the gain of having fluctuating rather than steady-state noise, and the benefit of binaural hearing with a directional separation of the test sentences from the noise (Duquesnoy, 1982). It was found that the advantage of these parameters is much greater for normal-hearing listeners than for aged subjects; in both cases average differences as large as about 7 dB were observed. This demonstrates that the deterioration of the auditory function with age results in a very serious hearing handicap in noisy environments.

THE EFFECT OF REVERBERATION

During the previous congress in Freiburg the role of the modulation-transfer function (MTF) in predicting the combined effects of noise and

reverberation on the speech intelligibility of normal-hearing listeners was briefly explained by Houtgast (1980). A more extensive treatment can be found elsewhere (Houtgast et al., 1980; Plomp et al., 1980; Wattel et al., 1981; van Rietschote et al., 1981; Steeneken and Houtgast, 1982; van Rietschote and Houtgast, 1983; see also Houtgast, this volume).

From the MTF between the location of the speaker to the location of the listener a single measure can be derived, the Speech-Transmission Index (STI) which appears te correlate excellently with speech intelligibility.

The success of this approach for normal-hearing subjects raised the question of whether the concept of D as a measure of the hearing loss for speech in noise can be extended to include the effect of reverberation too. This was studied (Duquesnoy and Plomp, 1980) for the condition that the listener is at a large distance from the speaker in a room with a diffuse sound field. In this case STI depends only on S/N ratio and reverberation time.

Recordings of the test sentences were made for various reverberation times up to T=2.6 sec. With these sentences the monaural speech-reception threshold of elderly subjects was determined, with the interfering noise fixed at a level of 52.5 dB(A).

The results are plotted in Fig. 4. The solid curves in this diagram represent STI as a function of reverberation time, with S/N ratio as the parameter. If the SRT values (= S/N ratios for which 50% of the sentences are understood correctly) for different reverberation times can be fitted by a horizontal line, we may conclude that STI is a good measure of the combined effects of noise and reverberation. The different symbols represent average values for a reference group (20 normal-hearing subjects, the plus symbols) and four groups of hearing-impaired subjects (14 to 29 per

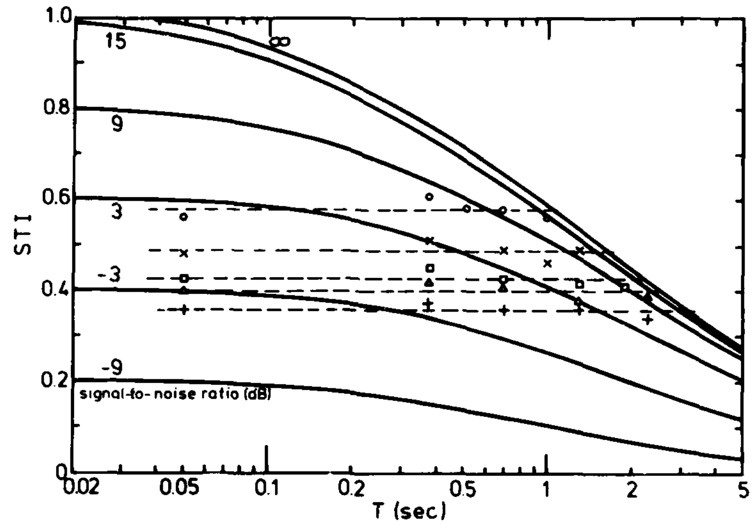

Fig. 4. The solid curves represent STI as a function of reverberation time, with S/N ratio as the parameter. The data points fitted by the horizontal lines give the average speech-reception threshold for sentences for a reference group (plus symbols) and four groups of hearing-impaired subjects (Plomp and Duquesnoy, 1980).

group) with increasing difficulties in understanding speech disturbed by reverberation. The fair agreement between the data points and the horizontal lines indicates that the trade-off between noise and reverberation given by the STI measure also holds for the hearing impaired (at least for the case of presbycusis investigated in this experiment).

This finding means a generalization of the rule that, without reverberation, every 3 dB of hearing loss for speech in noise can be compensated for by increasing STI by 0.1 (compare the S/N ratio in Fig. 4 with the ordinate scale). This rule also allows conditions with reverberation: the empirical finding that the acoustical conditions for understanding speech are fair for STI > 0.45 and good for STI > 0.6 implies that the corresponding values are 0.55 and 0.7, respectively, for subjects with a hearing loss for speech in noise of 3 dB, etc.

The higher STI values required to compensate for the hearing loss for speech in noise on the part of hearing impaired listeners can be achieved by improving S/N ratio and/or by reducing reverberation time. The S/N ratio increases when the speaker raises his voice level and when the handicapped listener shortens his distance to the speaker. The best way, however, of helping the hearing impaired is by reducing reverberation time. The following rules-of-thumb were calculated for two rather diverging conditions (Plomp and Duquesnoy, 1980): (1) in auditoria, classrooms, etc. most listeners are situated in the indirect sound field of the speaker and of the interfering noise sources; in this case the reverberation time T just acceptable for normal-hearing listeners has to be reduced to $(0.75)^D T$ in order to be equally acceptable to elderly subjects with a hearing loss for speech in noise of D dB; (2) in lounges, restaurants, etc. with the listener at such a short distance from the speaker that only the direct sound has to be considered, the situation is more favourable; in this case T has to be reduced to $(0.82)^D T$.

It may seem that these reduction factors for T of only 0.75 and 0.82, respectively, are a rather high price to pay for compensating for a hearing loss for speech in noise of only 1 dB. However, in terms of the percentage of subjects benefitting, the effect is quite substantial, see the vertical distance between each pair of successive curves in Fig. 3.

THE EFFECT OF NOISE-INDUCED HEARING LOSS

In a preliminary investigation (Smoorenburg, de Laat and Plomp, 1982) a group of 22 subjects with a noise-exposure history was tested. For left and right ears separately, the tone audiogram and the SRT as a function of background noise level were measured. From the latter data the D values after equation (2) were derived.

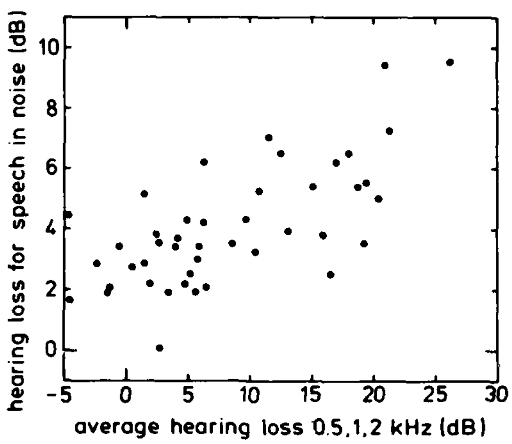

Fig. 5. Average hearing loss for speech in noise, D, as a function of the average value of the pure-tone hearing losses at 500, 1000, and 2000 Hz for the individual ears of 22 subjects with a noise-exposure history (Smoorenburg, de Laat and Plomp, 1982).

In Fig. 5 a scatter diagram of the values of D for the 44 individual ears as a function of the hearing loss for tones averaged over 500, 1000, and 2000 Hz is given. This is the well-known PTA (pure-tone average) proposed by the American Academy of Ophthalmology and Otolaryngology (AAOO) as a measure for the disability "to hear everyday speech under every day conditions". According to AAOO hearing is considered to be impaired if the PTA exceeds 25 dB. This would imply that in Fig. 4 for all ears except one no hearing handicap should be expected.

It is obvious that this measure, exclusively based on hearing loss in quiet,is much too optimistic for predicting the hearing handicap in noise. In our opinion, hearing loss for speech exceeding D=3 dB cannot be tolerated from a hearing-conservation point of view. Expressed in hearing loss for tones averaged over 1000, 2000, and 3000 Hz (a better correlate of D than PTA), this average should not exceed 15 dB. It should be realized that this value only holds as a group average. As Fig. 5 illustrates, the

correlation between D and the tone audiogram measured is so poor, that predictions of the hearing handicap for the individual should be based on the speech-reception threshold in noise rather than on the tone audiogram.

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ACKNOWLEDGMENT

This research was supported by the Ministry of Health and Environmental Protection of the Netherlands.

ACOUSTICS OF ENCLOSED SPACES FOR LINGUISTICALLY IMPAIRED LISTENERS.

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INTRODUCTION

It has been recognized and well documented that listeners with impaired hearing are effected by noise and reverberation at levels which are not detrimental for listeners with normal hearing. It is also apparent that the elderly can be adversly effected by less than perfect listening conditions. In case of the elderly, the perceptual problems are a combination of elevated pure tone thresholds and other deficiencies in sound analysis, such as a growing difficulty in proper differentiation of complex stimuli. Since the hearing impaireds and elderly can profit from improved listening conditions, the question arises as to whether they are the only groups who will benefit from properly designed acoustics. Several studies performed by us and others that refer to the above questions will be discussed.

It has been found that several groups of listeners with virtually normal hearing can also be affected by adverse listening conditions. These groups are: 1) children, 2) learning disabled, 3) non-native listeners, and 4) speech-impaired children. A common feature of these listeners

is linguistic skills different than normal native adults. While the learning disabled can be defined "linguistically impaired", the other three groups may not manifest any impairement, but their usage of language and probably their listening skills are less developed than those of normal native adults. In effect, they demonstrate some perceptual characteristics similar to groups linguistically deviant from norms.

Speech perception scores in an optimal listening condition, i.e., quiet and no reverberation, were compared to scores in more realistic conditions with noise or with reverberation. Sometimes noise may be more pervasive than reverberation, for example in small therapy rooms. Or reverberation may be the major factor degrading speech, as in quiet drama theaters. However, in many situations listeners are exposed to both noise and reverberation. None of the reported studies used a combination of noise and reverberation, but such conditions have been tested extensively with normal and hearing-impaired listeners (Nabelek and Pickett, 1974; Finitzo-Hieber and Tillman, 1978; Nabelek and Mason, 1981). It has been shown that the effect of noise and reverberation acting together is greater than a sum of effect of noise and reverberation measured separately. For that reason, the perceptual problems encountered by linguistically deviant listeners might be even more severe than those emerging from this report.

MATERIAL AND METHODS

Speech tests used in these studies were: the Modified Rhyme Test (MRT) (Kreul et. al., 1968), the sentence test of speech understanding in noise, SPIN (Kalikow et. al, 1977) and bisyllables designed specifically for the study with children listening in reverberation. All tests were recorded by male American talkers.

The MRT consists of 300 monosyllabic words arranged in 50 blocks of 6 words each. The words in one block differ only by either the initial or the final consonant. Each list contains 25 items for testing initial and final consonants. The words are spoken in a carrier sentence "Say the /test word/ again" at the rate of five syllables per second. The

task of the listener is to mark one of the six words he thought he heard. This test permits use of relatively untrained listeners, provides rather stable scores and minimizes any effects of familiarity of test words.

The SPIN test consists of 10 forms, each contains 50 sentences. For half the sentences in each list, the final key word (a monosyllabic noun) is predictable from the context (high predictability, HP); for the other half, the predictability of the final word is low (low predictability, LP). Examples of SPIN test sentences are: (HP) "The watchdog gave a warning growl"; (LP) "I am thinking about the knife". The task of the listener is to repeat the final word with an open set response. In addition to measuring word intelligibility, the SPIN test measures a cognitive component of speech understanding by providing two different scores for each: high and low predictability (HP and LP). This performance difference between the two sets of sentences for normal subjects is thought to be attributable in large part to the listener's ability to make use of the linguistic context of the HP sentences.

The stimuli used by Neuman and Hochberg (1983) were in a form of vowel-consonant-vowel disyllables in which each of three vowels /i/, /a/, and /u/ was combined with each of 19 consonants (all consonants with the exception of the semi-vowels). When recorded, the stimuli were preceded by the carrier phrase "Say the /disyllable/". The nonsense syllables were chosen because they are expected to be less subject to age factors than are meaningful materials, and thus would minimize possible congnitive effects.

In the studies where speech was degraded by noise, a babble of 12 voices was used as a masker. The babble had small level variations. Its spectrum was approximately parallel to the smoothed spectrum of male speech.

The reverberation was obtained by playing tests in rooms with controllable reverberation. Rooms used in the studies and recording procedures were similar. The volume of the rooms was about 160 m^3. The range of reverberation time (T) was between 0.4 and 1.2 s. The reverberation time was fairly even across frequencies (0.25 - 8 kHz). For speech processing, a Kemar manikin was placed in the reverberant field at a distance beyond the critical distance for the room. Sounds were picked up by microphones placed in the ear canals of the Kemar, passed through equalization filters designed by Killion (1979), and recorded on two tracks of a magnetic tape for sterephonic reproduction. These filters removed peaks at 2.7 kHz produced by the ear canals and eardrum impedance of the Kemar.

All subjects used in the reported studies had normal hearing as assessed by standard audiometric tests. The groups of children were normal in all aspects of learning, and differed from the reference group only by their chronological age. The learning disabled were young adults (ages 23-37) who had moderate or severe learning disabilities and who had received therapy for several years. They exhibited normal intelligence, but were described by their clinicians as having problems in word retrieval, auditory sequencing and memory, visual perception, and/or reading and expressive language. The non-native listeners were young and middle age adults (ages 21-48) who use fluent English as a second language. Their

native languages were various European and Asian languages. The speech-impaired children (ages 7-11) had normal intelligence and language skills but had been receiving therapy for articulation disorders.

Testing was done in sound-treated rooms. The speech recordings were played on tape recorders and presented to subjects through earphones. The speech was delivered at 60 to 70 dB SPL which is adequate to elicit the maximum score in quiet. If noise was added, it was played on another channel of the tape recorder and mixed with speech at specified speech-to-noise ratio (S/N). All testing with noise was performed monaurally. The tests with reverberation were also played at 60 to 70 dB S[illegible] and no noise was added. Testing was usually binaural and monaural but [illegible] monaural data will be discussed to allow for easier comparison wi[illegible] [illegible]ata collected in the noise condition.

RESULTS

Children. Speech perception of children in noise a[illegible] [illegible]everberation is shown in Figure 1. The results in the left panel are from a study by

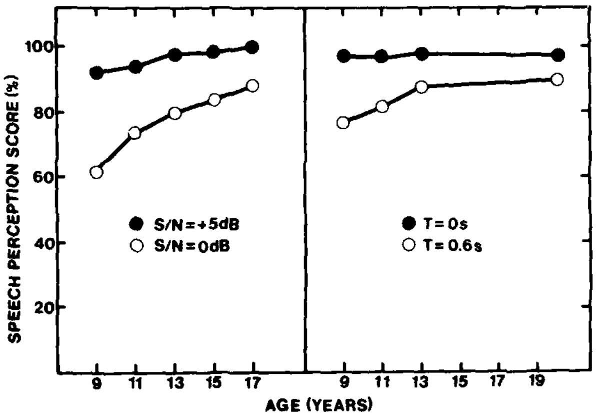

Fig. 1 - Speech perception of children in noise (adapted from Elliott, 1979) and in reverberation (adapted from Neuman and Hochberg, 1983).

Elliott (1979) and in the right panel from Neuman and Hochberg (1983). Elliott tested 24 children at each of four age levels (17, 15, 13, and 11 years) in a laboratory. Then she added results collected at schools with 9-year-olds. Children were tested with the SPIN at three S/N of +5, 0 and -5 dB. The data in the left panel of Figure 1 are for high predictability words (HP). The solid points represent S/N = +5 dB; open points

represent S/N = 0 dB. In the better S/N, all scores were high, but did decline slightly for 11-and 9-year-olds. Elliott believes that the SPIN is not appropriate for young children, and that the decline in scores reflects children's limited ability to use knowledge of lexical and syntactic contingencies and their diminished knowledge of language rules. In lower S/N, the scores declined with age even more rapidly which seems to indicate that the babble has a greater masking effect on the words of the sentence. It appears that children have less developed listening skills and cannot extract important information from the noisy background.

The same argument can be used for speech recorded with reverberation (right panel). Some data from Neuman and Hochberg (1983) are plotted to compare with Elliott's results. Neuman and Hochberg used nonsense syllables to test groups of children and young adults, five in each group. The age range was 5 to 20 years. Without reverberation, the 9-and 11-year-olds performed as well as older subjects indicating that, unlike SPIN, the nonsense syllables were equally difficult for all ages. This data is represented by the solid points on the graph. The test recorded in a room with T = 0.6 s produced a decline in scores for 11-and 9-year-olds while 13-year-olds performed as well as young adults. This data is represented by open points.

In another study, Nabelek and Robinson (1982) compared speech perception scores measured with the MRT of 10-year-old children and young adults. Ten subjects were tested in each age group. Scores declined gradually with reverberation. Children performed as well as adults when no reverberation was added. In three reverberant conditions, T = 0.4, 0.8, and 1.2 s, children performed an average of 6% worse than adults.

Learning disabled. Using the SPIN test, Elliott (1982) measured speech perception of learning-disabled adults at three S/N's. Subjects

had normal hearing in both or at least in the tested ear. The babble of voices was used as the noise. Data points on Figure 2 are medians of

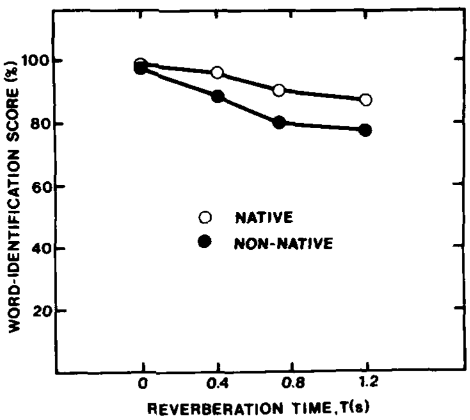

Fig. 2 - Speech perception of learning-disabled adults (adapted from Elliott, 1982).

scores for nine subjects. The data for another of Elliott's subjects are excluded from the medians because this subject had some hearing loss and his scores differed from the remaining group. In Figure 2, the solid points represent normal listeners and the open points represent learning-disabled listeners. Two upper lines denote low predictability (HP) words and the two lower lines denote low predictability words (LP). In the easy listening condition (S/N = + 10 dB), both groups obtained 100% correct scores. This indicates that these learning-disabled adults have learned to make use of linguistic context. Their greater difficulties seem to be with discrimination of basic sounds, as revealed by their poor performance on the low predictability (LP) sentences which have no contextual clues. Also, the learning-disabled subjects performed much poorer than do normals on both HP and LP sentences at S/N of 0 dB. The age Americans and similar-age non-native listeners was compared in our

problem of these listeners appeared to be directly associated with their poor auditory discrimination skills.

Speech-impaired children. Elliott (1982) reported some results for 7-to 11-year-old speech-impaired children tested with the SPIN. They performed as well as normal children their age when tested in quiet but obtained lower scores for HP and LP sentences in less favorable S/N conditions. Since data are unavailable for speech-impaired adults, it is not known if these type of listeners maintain their perceptual problem.

Non-native listeners. Bergman (1980) reported differences in speech perception scores for native and non-native listeners. During his research studies in the sixties, he observed that elderly listeners who spoke fluent but accented English obtained lower speech discrimination scores than listeners speaking without an accent. The difference was rather small for undistorted speech but increased to 20% for a variety of degradations such as machine-made speeding, long reverberation (T = 2.5 s), split band dichotic listening, and interruptions. Bergman (1980) repeated some of the studies using young Hebrew listeners (age 20-29). The native-born were matched to non-native listeners who had spoken another language at least until age of 7, but who had been speaking Hebrew for at least 13 years and were judged to be fluent in it. While undistorted sentences were perceived equally well by both groups, the scores for sentences in a babble of voices at S/N = + 3 dB were significantly lower for the non-native group. The difference was 13%. Bergman also tested elderly listeners and found that the difference for speech perception in noise for native and non-native groups tends to increase with age.

Speech perception with various amounts of reverberation by middle-

laboratory. Each group consisted of 10 subjects. The criteria for the non-native listeners were: 1) young or middle age, 2) normal hearing, and 3) at least 94% correct score using the Modified Rhyme Test without reverberation in quiet. The subjects' native languages were various European and Asian languages. The mean age of the ·native listeners, selected from the subjects tested previously (Nabelek and Robinson, 1982), had a mean age of 32.7 years, with a range of 25 to 52 years, and their hearing was normal. Thus, age and sex of the two groups were matched.

Speech perception as a function of reverberation time for native and non-native groups is shown in Figure 3. Scores are represented by open

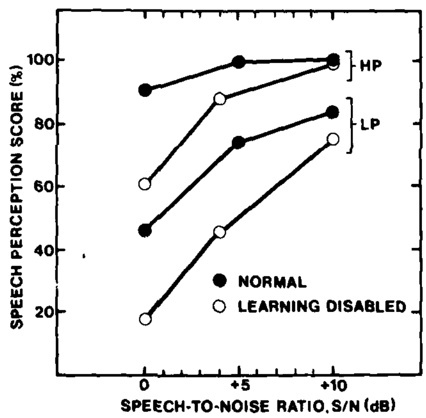

Fig. 3 - Speech perception of native and non-native listeners in reverberation.

and solid points respectively. The scores without reverberation were similar for both groups. With reverberation time of 0.4 s, the non-native listeners obtained 6% lower scores; with reverberation times of 0.8 and 1.2 s, they obtained 10% lower scores. The difference at T = 0.8 s and T = 1.2 s was significant ($p < 0.001$). These results indicate that non-native young and middle-age listeners who understand English very well in

the absence of reverberation might have difficulty understanding in the presence of even moderate reverberation.

The non-native group in our present study was linguistically heterogenous and the pattern of errors was not analyzed. Some errors are probably related to phonemes used in native languages. Singh (1966) pointed out that errors made the English and Hindu plosives for various conditions of band-pass filtering and temporal trunctuations differed for native and non-native listeners and for the two languages.

CONCLUSIONS

Results of these studies indicate that some listeners with audiometrically normal hearing might have problems understanding speech in noise and reverberation. The groups which are deviant from normal young adults are children below 13 years of age, learning-disabled adults, speech-impaired children, and non-native listeners. All these listeners obtained very high speech perception scores in quiet and without reverberation, but their performance was significantly lower than normal for more difficult listening conditions. They should benefit, as do hearing impaireds and the elderly, from specially-designed rooms having a short reverberation time and a very high S/N. They also should benefit from listening devices such as audio induction loops, FM and infra-red systems which have become popular in large auditoriums, churches and drama theaters.

The perceptual problems in less-than-optimal listening conditions of learning-disabled and speech-impaired children should be kept in mind when therapy rooms are designed. For normal children, the perceptual problems diminish with age. Apparently, listening skills can develop in real-life situations. However, good classroom acoustics might be helpful to improve attention and learning of small children. No data exist to indicate if all perceptual problems of non-native listeners decrease

with time of exposure to the language, but it is not very likely since some of Bergman's and our listeners had been using English or Hebrew for many years.

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ACKNOWLEDGEMENTS

The preparation of this paper was supported by a grant from the National Institute of Neurological and Communicative Disorders and Stroke, U.S. Public Health Service #R01 NS 12035.

I wish to thank Amy Donahue for aid in gathering data with non-native listeners.

PROPOSAL FOR A SCIENTIFIC PROGRAM

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After the meeting of Team 2, the proposal for a Scientific Program was summarized in five main points.

1. Much knowledge is already available on the effect of noise on communication and on the needs of the hearing impaired. Team 2 encourages initiatives to make this knowledge more generally available, including its consequences for design specifications.
2. More research is needed on the relation between a person's loss in speech understanding (or recognition of warning signals) and audiometric changes, as for instance noise-induced hearing loss.
3. There is a need for a systematic approach in defining the required degree of communication for specific categories of jobs and workplaces. This will provide a basis for (1) the definition of category-specific noise limits, and (2) the evaluation of a person's fitness (in audiometric terms) for a given category of jobs.
4. We need to know more about the effect of noise on various aspects related to speech communication, e.g. (1) noise and the use of synthetic speech, (2) noise and a non-native talker or listener and (3) noise and speaker identification.
5. With respect to the recognition of warning signals, more research is needed on the combined effect of noise and the use of ear protectors directional hearing in (reverberant) workspaces.

Poster Session

EFFECTS OF NOISE ON THE EFFECIENCY OF DANGER SIGNALS

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INTRODUCTION

Danger signals play an important role in the attempt to avoid harm or danger to life of working people. Effective signalling should rest on combination-standards of signal and danger to be indicated. In fact such norms do not exist and therefore a research project is carried out to find out signals which are optimized with respect to a number of criteria (cf. BOCK, LAZARUS & HOEGE, 1982). One of these criteria is the stability of signal interpretation. Because there are varying noise levels in factories, efficient signals should not be altered in their judged dangerousness by different noise levels. The question arises, whether signals can be identified experimentally which are not affected by different levels of noise. The variable 'dangerous - not dangerous' was chosen, because it had been demonstrated by previous experiments that signals rated as dangerous lead to associations that are rated as dangerous, too. For this reason the dimension of dangerousness has to

be regarded as an efficient index of relevant interpretation of danger signals.

MATERIAL AND METHODS

Fourty-eight students of different fields of Ruhr-Universitaet Bochum took part in this (paid) experiment. Each subject rated 36 signals in total, 9 of these were presented under 90 dBA signal and 95 dBA pink noise, 9 under 90/85 dBA, 9 under 90/45 dBA, and 9 signals under 70/45 dBA. Four different sequences of signal-to-noise conditions were developed to control order effects, each sequence was judged by 12 subjects. Signals were rated on a 7-point scale: not dangerous (1) - dangerous (7). Twenty danger signals are of special interest in this context. The remaining 16 signals were partly synthesized by Westdeutscher Rundfunk Koeln, partly produced by help of electronic music instruments. They were designed as distractors to differentiate between danger- and not-danger-signals.

RESULTS

For restrictions due to the BMDP computer program we had to analyze the ratings of dangerousness by 4 two-factorial ANOVAs. The first factor is S/N-ratio (with 4 levels), the second is defined by acoustic signals (with 9 levels). Three analyses produced significant interaction effects ($p \leq .02$), showing that the included danger signals are differently affected by noise levels. Therefore the interactions were checked by making tests on simple effects (WINER, 1971). Significant results of these tests are given in table 1, means and descriptions of signals are shown in figure 1.

Table 1: Simple effects of danger signals influenced by noise levels (cf. figure 1)

danger signals	$F_{3/44}$	p
I1 (bell)	13.15	.00
I2 (bell)	3.12	.04
I4 (impulsed sound)	9.68	.00
R1 (square wave)	6.30	.00

In the fourth ANOVA only the two main effects were highly significant (S/N-ratio: $F = 5.67$, df: 3/44, $p < .003$; signals: $F = 17.63$, df: 8/352, $p < .0001$) whereas the interaction was not ($F \approx 1.37$, df: 24/352, $p > .11$). Thus, danger signals included in this analysis are equally influenced by noise levels with respect to their judged dangerousness (St, Sh, I3, S1, S4; cf. figure 1). Danger signals not significantly influenced ($p \geq .08$) by different S/N-ratios are the following: H1, H2, H3, H4, T, S2, S3, S5, Sk, Q, Rs; cf. figure 1).

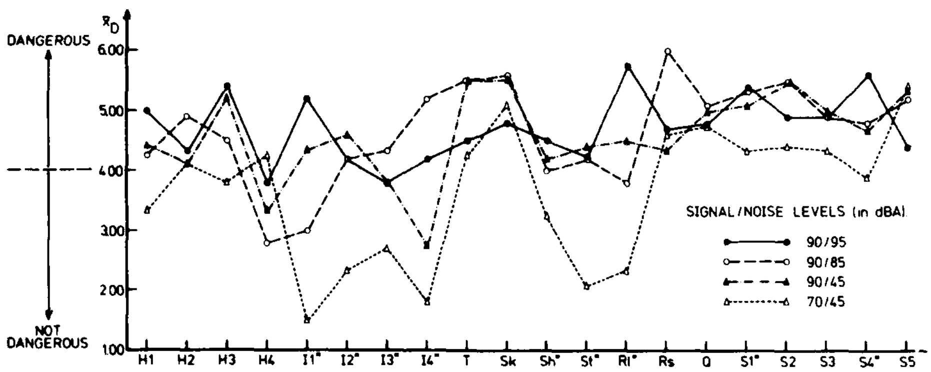
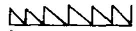
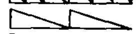


Figure 1: Mean dangerousness of 20 danger signals judged under 4 S/N-ratios. *= significantly influenced by S/N-ratios. Abbreviations and descriptions of danger signals are given below.

abbr.	description		
H1	horn, freq. range 0.3-4 kHz		
H2	horn, freq. range 0.08-0.8 kHz		
H3	horn, freq. range 0.8-3 kHz		
H4	horn, freq. range 0.4-5 kHz, pulsed		
I1*	bell, freq. range 0.1-5 kHz, slow pulsed 1 Hz		
I2*	bell, freq. range 0.1-5 kHz, fast pulsed		
I3*	impulsed sound, freq. range 1-4 kHz, pulsed 4 Hz		
I4*	impulsed sound, freq. range 3-5 kHz, pulsed 4 Hz		
T	Typhon, freq. range 0.6-4 kHz, horn-like		
Sk	sirene, const. freq., f_o= 0.6 kHz, freq.range 1-3 kHz		
Sh*	pure tone 2 kHz		
St*	pure tone 0.5 kHz		
R1*	square wave, f_o= 1 kHz, pulsed 0.5 Hz		
Rs	square wave, f_o= 2 kHz, pulsed 1 Hz		
Q	quarte sequence, f_o= 0.85-1.15 kHz, pulsed 1 Hz		
S1*	sirene, freq. mod.: f_o= 0.5-1.2 kHz,		3 Hz
S2	sirene, freq. mod.: f_o= 0.5-1.2 kHz,		1 Hz
S3	sirene, freq. mod.: f_o= 0.5-1.2 kHz,		0.5 Hz
S4*	sirene, freq. mod.: f_o= 0.5-1.2 kHz,		1 Hz
S5	sirene, freq. mod.: f_o= 0.5-1.2 kHz,		1 Hz

CONCLUSIONS

9 of 20 danger signals are significantly influenced by different S/N-ratios. These signals are not suitable as effective warnings because their judged dangerousness will be affected by noise: S/N-levels in factories are not constant and therefore only danger signals not influenced by noise are appropriate as effective warnings. Eleven of the investigated danger signals do meet this criterion, but it should not be the only one. It has to be taken into account whether the rated dangerousness of a signal is strong enough to cause the recipient to associate dangers when warned. A further criterion is the compatibility of signal and danger-situation it has to stand for. Research into this topic is still in progress. The aim is to standardize the application of danger signals.

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Team No. 3

Non-Auditory Physiological Effects Induced by Noise

Chairman: J.H. Ettema (The Netherlands)
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Invited Papers on Specific Topics

RESEARCH ON EXTRAAURAL EFFECTS OF NOISE SINCE 1978

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Bundesrepublik Deutschland

INTRODUCTION

Like in earlier years many investigations since 1978 were carried out under laboratory conditions examining one or several physiological functions influenced by noise alone, or in combination with other influences, like vibration, mental task, physical effort and others. Usually the subjects used, were classified as healthy male volunteers, what means universitary students, in order to keep the group homogeneous. In some studies relations between cognitive aspects, personality factors and physiological responses were also taken into consideration. The acoustical stimuli which were applied varied quantitatively in terms of noise intensity or qualitatively in terms of the type of noise, e.g. broadband noises, traffic or aircraft noise. A considerable number of field studies were also carried out to investigate chronic noise exposure in unselected samples in their accustomed environmental conditions. In the conducted experiments noise was often considered to be a stressor, but it was often not quite clear whether the investigator himself had judged this kind of experiment to be stressful to the subjects or whether the subjects themselves had estimated the noise to be stress-

ful. It is not always clear, what scientists mean when they use the term "stress", e.g. whether they refer to psychological or physiological parameters (BARTHOLOMEYCZIK 1981). The use of animal models to study the effects of noise has decreased in the last years. One reason may be that it is in general very difficult to extrapolate from animal studies to humans. In determining the effects of noise directly on the ear, animal studies were very helpful, especially for histological analysis of the development of detrimental morphological changes. Concerning the evaluation of extraaural effects, results from animal studies initiated good ideas for research on humans, for example studies concerning fertility or teratism. It is also still very important to use animals when extreme or dangerous conditions forbid experiments with humans for ethical reasons. However, for assessing the effects of occupational and/or environmental noise, results from animal experiments often fail to give an answer to the question of "how much is too much in our daily life", i.e. what noise level can be accepted or which combination with other environmental factors is tolerated before health is impaired. These relationships also cannot be satisfactorily explored in laboratory experiments with humans. Therefore multifactorial field studies are required. This was one of the aims, which was strongly emphasized at the last congress 5 years ago.

VARIOUS VEGETATIVE REACTIONS

In various studies, mostly under laboratory conditions, the effects of sound stimuli on some selected vegetative reactions were examined: respiration, heart rate, cutaneous blood flow, constriction of peripheral blood vessels, skin temperature, tremor, secretory function of stomach, bowel transit, bioelectrical activity of the brain and cerebral circulation (BÄTTIG 1981; CARSTENS 1980; ERCKENBRECHT 1983, FRUHSTORFER & HENSEL 1980; KHAIMOVICH 1978; KIEC 1977, KRYTER

& POZA 1980; MIYAZAKI 1978; NEUS et al. 1980; SORG 1979). The meaning of the observed changes, particulary the effects on peripheral blood circulation, is still in discussion. For example it is not clear whether they are to be considered as physiological responses, more related to auditory, reflexive protective mechanisms, psychic processes or whether they implicate autonomic system responses, generally considered to be harmful to the organism (KRYTER & POZA 1980, GUSKI 1980). In other studies physiological reactions were examined in the field situation, in oder to investigate the possibility of finding different patterns of reactions, influences of psychic factors or the possible development of coping mechanisms with chronic noise load (BÄTTIG et al. 1980; GUSKI 1980).

BIOCHEMICAL EFFECTS OF NOISE

Effects on the blood lipid fractions were studies by CERVINKA et al. (1980a, b), VERDUN di CANTOGNO (1976), ISING et al. (1980a, 1981a), MANNINEN & ARO (1979b) and by RAI et al. (1981). Application of noise as a stress factor in laboratory experiments led to a decrease in triglycerides in connection with an increase of free fatty acids and phosphatids. The results concerning cholesterol are contradictory, - while CERVINKA et al. (1980a, b) found a decrease of cholesterol, the other investigators reported elevated levels of cholesterol due to noise in laboratory as well as in field studies. SANDEN & AXELSSON (1981) found higher mean cholesterol levels for those workers with the most noise-induced hearing loss. This result could support the hypothesis, that risk factors of arteriosclerosis are mutually combined with the deleterious effects of noise on man.

In laboratory as well as in field studies blood glucose was found to be slightly augmented by noise (CERVINKA et al. 1980a, b; VERDUN di CANTOGNO et al. 1976; MANNINEN & ARO 1979b).

Effects on serum protein levels including the albumin/globulin ratio were investigated by RAI et al. (1981) and TURCZYNSKI et al. (1978). There seems to be an increase of gamma globulin induced by chronic noise exposure. Concerning the effects of noise on cortisol and its metabolites BRANDENBERGER et al. (1977) did not find any change under experimental noise exposure, while YAMAMURA et al. (1982) reported a significant increase in urinary 17-OH-CS and an initial effect on saliva cortisol. In combination with a mental task BRANDENBERGER et al. (1980) also found elevated plasma cortisol levels, possibly due to the higher degree of strain or to influences of cognitive variables. In field studies SKWARNA et al. (1980) and RAI et al. (1981) observed higher cortisol levels in chronic noise-exposed workers.

The effects of noise on epinephrine, norepinephrine and their derivatives were investigated in many studies (ANDREN 1982b; ANDREN et al. 1978; DOBRZANSKI & RYCHTA 1977; ISING et al. 1980a, 1981 a, c; KLOTZBÜCHER & FICHTEL 1978, 1979; MAKOTCHENKO 1978; CESANA 1982a, b; MANNINEN & ARO 1979b; BRANDENBERGER et al. 1980). Under laboratory conditions and in field studies noise increased epinephrine or norepinephrine or both in most of the investigations. It was not quite clear, why sometimes epinephrine and at other times norepinephrine was influenced. To explain such conflicting results ISING et al. (1981c) proposed the following interesting hypothesis: Noise exposure to which the subjects are used stimulates nerve fibers with synapses in the vascular system, which, therefore, leads to an elevation of norepinephrine levels. Noise exposure, to which the subjects are not accustomed represents a higher degree of stress and stimulates the adrenal glands, which leads to augmented levels of epinephrine. The effects of noise on dopamine, growth hormone or plasma angiotensin II as indicators of sympathetic activity did not yield reliable results, probably due to wide distribution or difficulties in measuring (ANDREN 1982b; CESANA 1982b; BRANDENBERGER et al. 1980; WRIGHT 1981).

The effects of noise on the magnesium (Mg) metabolism were studied by ISING and his colleagues (1981a, b, c). In animal studies, in laboratory experiments and in field studies they observed changes of Mg in relation to noise. Due to the biochemical effects of the released catecholamines, serum Mg is increased as a result of intracellular losses, which leads to a higher excretion in the urine. Under chronic stress and with a marginal supply of Mg provided by food, as it is usual in industrialized nations, a chronic negative Mg-balance may be induced. Decreased Mg levels are followed by intracellular increases of Ca, for example in the heart muscle, which increases vasoconstriction and sensitizes the muscle for catecholamines. These processes may be one of the keys for the understanding of the development of cardiovascular diseases by noise.

EFFECTS OF NOISE ON CRITICAL GROUPS

Depending on varying susceptibility and to particular environmental or health conditions, it is assumed that for some special groups of the population there may be a different, possibly more critical risk of health impairment due to noise. In some laboratory studies subjects suffering from essential hypertension were examined concerning their responses to noise (ANDREN et al. 1981; ANDREN 1982, HÄCKER 1980; SCHULTE et al. 1977). They did not differ from healthy subjects in blood pressure response but reacted stronger, longer and at lower intensities in peripheral vasoconstriction. The lack of differences in blood pressure response in hypertensive persons could be explained by alteration of the elasticity of the blood vessels due to long lasting effects or to mechanisms of counterregulation. In discordance with these results on manifest hypertension v. EIFF et al. (1981) and NEUS (1981) speculated that subjects with a genetic predisposition to essential hypertension run a higher risk to suffer from the deleterious effects of noise

than others. They found that persons with hereditary disposition for hypertension had significantly higher blood pressure responses than the controls. Concerning special pharmacological treatment to hypertensive persons no essential difference in noise response could be seen after applying beta-adrenoceptor blockade drugs. Using alpha$_1$-adrenoceptor blockade the total peripheral resistance response was blocked (ANDREN 1982a).

In order to elucidate individual differences of responsiveness to noise, persons with particular individual caracteristics were tested. Subjects with higher lability of the vegetative system showed no different responsiveness in peripheral vasoconstriction or galvanic skin response to noise than those with a stable vegetative system (BERNSDORF 1980). In contrast to these findings from laboratory experiments, done with healthy students, BÄTTIG et al. (1980) concluded from a field study carried out near Zürich airport that general vegetative lability might be a prerequisite for vegetative responsiveness. Other studies were done on subjects who could be caracterized as coronary prone (type A) or non-prone (type B). The coronary prone subjects reacted quite differently not only in vasoconstriction but also in biochemical parameters (LOVALLO 1980; ICKES & ESPILI 1979). Yet, in heart rate and blood pressure no differences were seen.

Already in earlier years it was supposed that if noise might have deleterious effects on the health of normal humans, there might be also an effect on pregnant women. These effects may be caused by maternal endocrine or circulatory changes due to noise exposure. REHM & JANSEN (1978) as well as KNIPSCHILD et al. (1981) examined retrospective data of obstetric records. Both studies indicated a positive relationship between aircraft noise and a reduced birth weight or an increase in percentage of premature births. However, the effects were very slight and not statistically significant. SCHELL (1981) also did not find a statistically significant

reduction of birth-weight as a function of exposure to aircraft noise. But he found a large negative partial correlation coefficient for noise exposure and gestation length in girls. In boys statistical significance was not quite reached. FRITZSCH (1979) did not find any difference in the physiological response of women, pregnant women and men. Fetal heart response seemed to be unchanged up to L_{eq} 90 dB(A). To be more prudent he recommends, that exposure of pregnant women should not exceed noise levels of L_{eq} 80 dB(A). Another possible influence of noise on the human fetus can be expected in teratism. EDMONDS et al. (1979) found no significant difference in the incidence of birth defects while JONES & TAUSCHER (1978) report a significant difference due to noise. The Committee on Hearing, Bioacoustics and Biomechanics (1982) reviewed the human and animal data available so far on prenatal effects of exposure to high-level noise. Neither in human studies nor in animal experiments was there a clear evidence for the influence of noise on pregnancy. With regard to direct aural effects on the fetus the fetal ear can be assumed to reach functional maturity by 26 weeks gestation. The background intra-uterine sound level is about 70-85 dB SPL, probably generated by the mother's circulatory system and bowel movements. External airborne noise is attenuated in the range 25-30 dB, high frequencies about 50-70 dB. From a prophylactical viewpoint they suggest that a mother should avoid exposure to noise which exceeds 90 dB SPL until better information is available.

MENTAL HEALTH, NEUROVASCULAR DISORDERS AND MORTALITY RATE

Various studies have dealt with the relationship between mental health and noise exposure (BROADBENT 1980; CUESDEAN et al. 1977; JENKINS et al. 1979; MEECHAM & SMITH 1977; TARNOPOLSKY et al. 1978; TARNOPOLSKY et al. 1980; WATKINS et al. 1981; SKWARNA et al. 1980; SUVOROV 1979). Psychoneurotic and psychosomatic complaints seemed to be higher as

a result of work noise and aircraft noise load. The effects were stronger in those subjects who felt more annoyed and who were more sensitive to noise. In addition, the uptake of psychotropic drugs and the use of medical services was higher in those who felt more annoyed.

MEECHAM & SHAW (1979) examined the mortality rates in residential areas near Los Angeles International Airport in comparison to a control area. They found an increase in deaths due to stroke or cirrhosis. Unfortunately there was a large gap between the deaths reported and those recorded by Los Angeles County, so that their findings did not remain undisputed.

EFFECTS OF NOISE ON THE CARDIOVASCULAR SYSTEM

The effects of experimental exposure to noise of various types on cardiovascular responses were studied by ANDREN et al. (1978, 1980), v. EIFF et al. (1981), ISING et al. (1980a, b), PARROT (1981), PETERSON et al. (1981) and YAMAMURA et al. (1981). Generally, attention was paid to the elevation of blood pressure. In most of the studies significant increases in diastolic and/or systolic blood pressure could be observed. Keeping these results in mind it was suggested that these physiological sympathetic responses would lead to permanent elevation of blood pressure which would contribute to the development of arterial hypertension. This hypothesis that noise exposure might be a risk factor to health, especially for the development of cardiovascular disorders has already been formulated for years, but we are still far from knowing the risk and the explicit mechanisms and the moderating effects from other environmental or intrapersonal factors. Some epidemiological investigations were conducted to determine whether chronic noise exposure at work or at home is likely to cause cardiovascular disorders, augmented blood pressure levels or even to induce hypertension (BAUER et al. 1980;

BRITANOV 1979; CUESDEAN et al. 1977; COHEN et al. 1980, 1981; v. EIFF et al. 1980, 1981; KHAIMOVICH 1979; KNIPSCHILD 1979; MANNINEN & ARO 1979b; MALCHAIRE & MULLIER 1979; RAZVEIKIN et al. 1980; SINGH et al. 1982; VILLA 1980). Most of the studies pertain to occupational noise. This fact may be due to facilities of controllable noise conditions, sample drawing, volunteering, financial support etc. Concerning blood pressure levels SINGH et al. (1982) found an increase of both systolic and diastolic blood pressure in workers exposed to noise levels of 88-107 dB(A) for 10-15 years, whereas MANNINEN & ARO (1979b) reported an elevated systolic blood pressure. CUESDEAN et al. (1977) and BRITANOV (1979) found higher rates of borderline or manifest arterial hypertension among noise exposed workers, while MALCHAIRE & MULLIER (1979) did not observe a significant difference in prevalence of hypertension among workers exposed to noise levels of 95 dB(A) in comparison to a control group. In addition to changes in blood pressure other cardiovascular parameters were examined. SINGH et al. (1982) described irregularities in cardiac rhythm, KHAIMOVICH (1979) saw higher rates of hyperkinetic cardiac syndrom, VILLA (1980) stated remarkable changes in systolic time intervals and CUESDEAN et al. (1977) reported alterations in ECG records.

The effects of traffic noise were epidemiologically studied by KNIPSCHILD & SALLE (1979) and by v. EIFF & NEUS (1980). V. EIFF & NEUS (1980) studied a mixed sample of 931 persons and found a higher rate of hypertension in the traffic noise areas. The duration of medical treatment correlated with the time of noise exposure. In the population study of KNIPSCHILD & SALLE (1979) only housewives (40-49 years) were included. No differences were found in the occurence of consultation with a cardiologist, hypertension, angina pectoris, ischaemia on ECG and heart shape pathologics on chest X-rays. The lack of a difference between these two groups of women is not very surprising since the risk of suffering from cardiovascular diseases is still very low in

women at that age due to the protective effect of their female hormones, so that influences of environmental factors may be masked. RAZVEIKIN et al. (1980) found alterations of moderate degree in people living and/or working at airports. He reported alterations like reduced myocardial contractility, predominance of the sympathicotonic type of cardiac activity regulation and increased rigidity of elastic vessels.

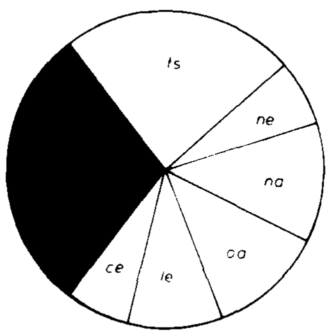
As summarized above, in many experimental conditions short-term exposure to noise often induced immediate increases in diastolic and/or systolic blood pressure and showed many other sympathetic and especially biochemical responses, which are considered to be risk factors to the cardiovascular system. Nevertheless, the question of, whether prolonged exposure to occupational or environmental noise is associated with elevated blood pressure or higher cardiovascular morbidity is still in discussion. However, from the given findings another, interesting reciprocal action can be hypothesized: Cardiovascular disorders, subclinical or clinical present or even expected from hereditary history, could influence the possible effects of noise. In 1977 JONSSON & HANSSON published findings about an association between hearing loss and elevated blood pressure. They concluded from the presence of hearing loss to the degree of noise exposure and assumed that the noise load had caused both hearing loss and elevated blood pressure. Another view of these findings would be that those subjects who develop hearing loss also have a predisposition to cardiovascular diseases. The connection between noise induced hearing loss and blood pressure was then studied by other investigators (LEES & HATCHER-ROBERTS 1979; TAKALA 1977; HEDSTRAND et al. 1977; SANDEN & AXELSSON 1981; MANNINEN & ARO 1979a). No clear evidence was found that hearing loss and blood pressure are associated. MANNINEN & ARO (1979a) found differences in the older age groups only for the subjects with moderate degree of hearing loss, - in the group suffering severe hearing loss the differences in blood pressure were slight.

DEMETER et al. (1979) examined workmen from a mining enterprise. From his results he concluded that noise exposure acts as an inductor of arteriosclerosis. Moreover he reported that those subjects, who had risk factors for atherosclerosis and also had manifest clinical symptoms, had a higher risk of suffering from hearing loss. The extent of hearing loss was in closer connection to the severity of atherosclerosis than to the duration of noise exposure. This result can be supported by findings in animal studies done by BORG (1981) and BORG & MØLLER (1978). Lifelong noise exposure influenced the blood pressure neither in spontaneous hypertensive rats nor in normotensives. In the histological examination of surface prepared cochleas the number of hair cells was diminished. The authors concluded that genetic hypertension might itself predispose for hearing loss in noise.

THE SIGNIFICANCE OF NOISE AS A RISK FACTOR

Results from epidemiological studies carried out many years before (e.g. DFG 1974) could clearly show that the simple stimulus-response concept cannot sufficiently explain complex relationships. The research on noise effects must include the moderating influences of other factors which change the response of the organism exposed. These factors may be his environmental conditions, his learning history, his attitudes, his socioeconomic status etc.. Moreover, mutual effects can be expected when several environmental factors are interacting. Therefore the risk of noise-induced impairment will depend on interaction with other environmental variables. In an own investigation carried out on employees of a military service unit we tried to determine the importance of noise among other occupational or personal risk factors. The state of health of the employees was judged by a thorough physical examination and by a standardized questionnaire referring to their actual complaints, use of drugs, medical treatment and actual and former diseases etc..

For each subject a score was composed, resulting from the physical examination and from the answers to the questionnaire, indicating the degree of health impairment. Their occupational and personal load was partly measured and partly subjectively evaluated by the subjects themselves. By multiple determination analysis we tried to explain the variance of general health state of the employees by the influences of their occupational exposure to several noxious conditions (fig. 1). Time stress proved to be the most important factor



	r sig	b sig	d	r part sig	impairment
time stress	0.414 •	0.576 ⋮	23.9%	0.714 ⋮	yes
noise exposure	0.337 ns	0.204 ns	6.9%	0.246 ns	4-23 years
noise annoyance	0.428 •	0.281 ns	12.1%	0.363 ns	extreme, much
odour annoyance	0.361 ns	0.321 ns	11.5%	0.315 ns	extreme, much moderate
lead exposure	0.250 ns	0.398 •	10.0%	0.432 •	4-20 years
carbon disulphide exp	-.095 ns	-.678 ⋮	6.4%	-.656 ⋮	nc
multiple	0.84.		70.8% :		

r = correlation coefficient b = beta, d = determination, r part = partial correlation
sig = significance level ns = not significant • ≤ 5 % (p ≤ 0.05) : ≤ 1% (p ≤ 0.01) ⋮ ≤ 0.1% (p ≤ 0.001)

Multiple determination of
general health - state (sum - score)
of 29 employees (technical administration section and tank maintenance and testing section)

TM 27 886

Fig. 1

in relation to health impairment. Next in importance is noise annoyance and then nearly equivalent odour annoyance, resulting from exposure to several chemical agents, appears to be essential. This may be a hint, that those who suffer from higher degrees of health impairment may be more sensitive to

annoying conditions. In the same manner it could also mean that they suffer more from time stress. Whether these factors are in causal connection with health or whether they are only coincident indicators of a higher sensitivity is still not quite clear. Probably this question can be answered only after some years of research with the same sample. Duration of exposure to noise is an essential factor for general health state, also, but in comparison with the others it seems to be less important.

Further information can be gained by separating the score of general health state into its components of organ related disorders (fig. 2). Only the most important results shall be

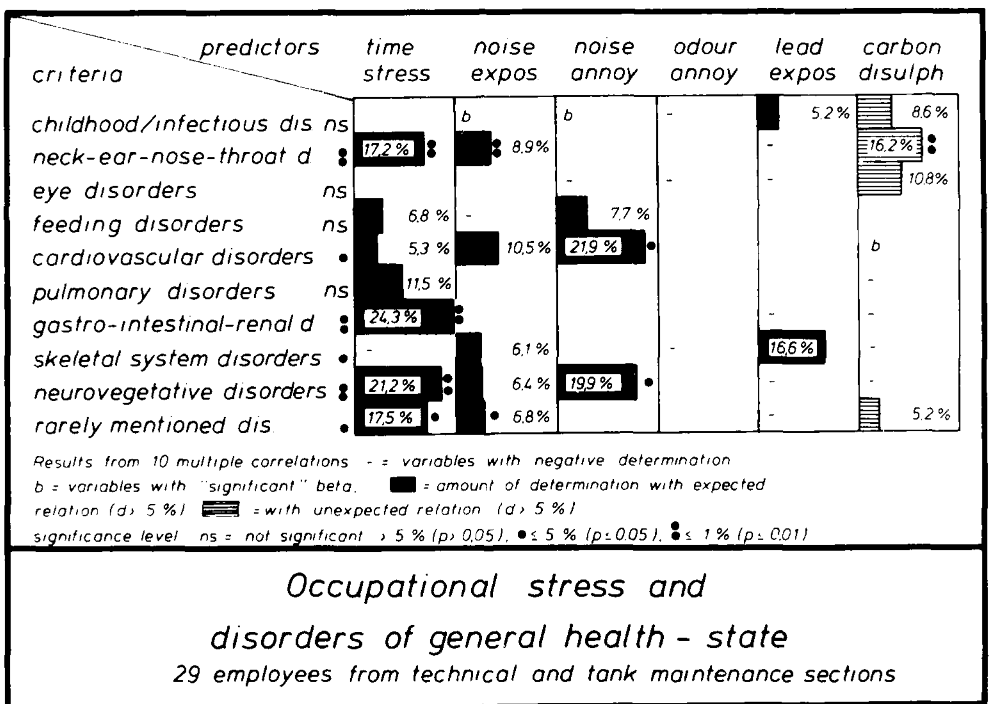


Fig. 2

pointed out here. Time stress seems to be important for

gastro-intestinal disorders, neurovegetative disorders and diseases of neck, ear, nose and throat; the latter may be perhaps due to a higher risk of viral infections. Concerning noise a very striking effect has to be emphasized: Cardiovascular disorders are mainly determined by duration of noise exposure and by the degree of noise annoyance. In addition noise plays a role in neurovegetative disorders and diseases of ear, nose and throat.

These results show how the risk of noise can be assessed by use of a multifactorial research design. Obviously, further investigations are required to determine the importance of noise for human health and to assess its harmfulness in relation to other occupational, environmental or personal influences.

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LATE POSTNATAL EFFECT ON CORTICOSTERONE BLOOD LEVEL, OF AN ACOUSTICAL STIMULATION PREVIOUSLY APPLIED TO MICE DURING PRE OR EARLY POSTNATAL LIFE.

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INTRODUCTION

Considering that the fetal period consists of different phases of development in each or all of which the fetus might be particularly sensitive towards certain stimuli, we stimulated mice during different period of their pre and postnatal life to a high intensity sound, which was again given at 21 days.

In a previous paper (Busnel and Molin, 1978) we had reported that exposure to loud noise 4 h/day during fetal life had little effect on the development of mice pups if mothers were not otherwise stressed.

However, mothers who were exposed at the same time to loud noise and a combination of other stresses showed higher abortion rates, an increase in cannibalism of pups at birth, smaller and ligher litters. This weight loss was still perceptible at 42 days (just prior to sexual maturity). The additional stresses included separation of mothers from their mates and pups, grouped in cages of 10 during the 4 h sound stimulus, and slight shaking for 2 or those hours.

Thus noise, 4 h a day, did not by itself have a teratogenic effect, but association of several stresses did* (* : see next page).

Considering that noise in itself was not a stress for the fetus, we divised another serie of experiments reported here, the purpose of which was to test a further hypothesis :
Any noise if heard prenatally will be considered by the young animal as

"known" and will therefore not be stressful when given again after birth.

As in the previous experiment, we used deaf and normal hearing mothers so as to determine possible effects of the mother's reaction on the pup's reaction to these stimuli.

All reactions were tested through corticosterone assays.

MATERIAL AND METHODS

1. Experimental animals

Normal hearing G.F.F. (+/+) were used as breeders, as well as their mutants (dn/dn) which are genetically deaf. By cross breeding a hearing male with a deaf female or a deaf female with a hearing male we obtained for experimental purposes hearing hybrid pups either of hearing or of deaf mothers ; all litters are culled to 6 pups.

2. Method of prestimulation

All stimulation was performed in an 33 m3 anechoïc room with programmed light and temperature. Mice were brought in this room only for the period of stimulation and brought back to the breeding room afterwards.

We will here after call, prestimulation the sound used to stimulate the animals during fetal and postnatal life and poststimulation that sound used at 21 days - just before blood sampling.

3. Acoustic frequency of prestimulation

a) complex noise assimilated to a white noise (in fact a recorded subway noise at 106 dB)**
b) pure frequencies at 16 kHz continuous or impulsif
c) pure frequencies at 10 kHz continuous or impulsif
d) pure frequencies at 5 kHz impulsif only.

4. Time of acoustic prestimulation

Sound was given 4 times a day for one hour at intensities from 102 to 106 dB at different periods :
1. from conception to birth
2. from birth to 9 days (maturation date of the auditory system)
3. from 9 days to 21 days

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* The fact that any abnormality is amplified by an extra stress seems confirmed in one of the experimental groups where a high degree of abnormal pups (1 %) were found even in the controls (normal rate was in our animal of 0,2 or 0,3 %). Whether this high rate was due to experimental procedure or genetic factors was not possible to determine, but the multiple stress group of this serie showed a rate of 6,85 % fetal abnormality (particularly anencephalies and exocephalies). This result being unique in the long serie of experiments we performed it was concluded that this group had been subjected to an extra stress, as compared to the others.

** Subway noise was emitted with a Lansing, Type LE 15 loudspeaker, for medium and high frequencies (from 500 Hz to 14 kHz) and a Lansing, Type LE 375 for the lower ones. Pure frequencies were given through Motorola piezoelectric tweeters placed 33 cm above the cages.

testing the hypothesis for normal distribution and calculating the probability density of t (exact probability for a two-tailed test). The values obtained for the control and experimental groups were compared using a Chi-suare test for 2 variables and with 1 degree of liberty.

9. Principle of the corticosterone assay used

This technique exploits the affinity of a corticosteroid (here corticosterone) for a specific natural binding protein (Corticoido Binding Globulin) present in the plasma of most vertebrate species (Murphy, I964).

It is based on the competition between the corticosterone present in an ethanol extract of the plasma sample to be tested and a known quantity of tritiated corticosterone pre-bound to transcortine (Murphy, I967). When the corticosterone (tritiated and cold) unbound to transcortien is eliminated by absorption on magnesium silicate (florisil), the quantity of tritiated corticosterone bound to transcortine (and therefore not adsorbed by the florisil) is inversely proportional to the quantity of cold corticosterone present in the ethanol extract. By comparing the degree of transfer brought about by known quantities of cold corticosterone (standard curve), the corticosterone content of the sample tested can be measured.

RESULTS

I. Preliminaty studies

A number of verifications were performed so as to exclude certain extraneous variables :

A. Lenght of time between beginning and end of sampling : no correlation was found.

B. The auditory state of the mother does not affect the results except in a few cases of those treated from conception to birth. In all other cases, pups of hearing and deaf mothers will be included in the same groups.

C. We were able to achieve 12 experimental days* during which from 200 to 300 samples could be collected each time - we therefore accumulated some 3 370 samples, control and treated animals (this includes a number of samples duplicate).

D. Since large variations were observed in the results it was hypothetized that more emotional mice would have higher levels of corticosteroids after acousitcal stimulations. This was not confirmed after a number of open field tests, since no correlation could be found between levels of corticosteroids and any of the open field features. (Total number of passages

*Each experimental day being preceeded by 45 days (21 from conception to birth and 21 days after birth) of preparation and preatreatments, 12 experimental days is the maximum possible in 24 monts.

in each case, number of passages in the central cases, number of jumping, duration of immobilization, number of feces, toileting, etc.).

II. General results

After pooling all treated groups irrespective of day or type of stimulation, one compared them with all controls all together 3 370 samples of which 430 controls (Fig. 1).

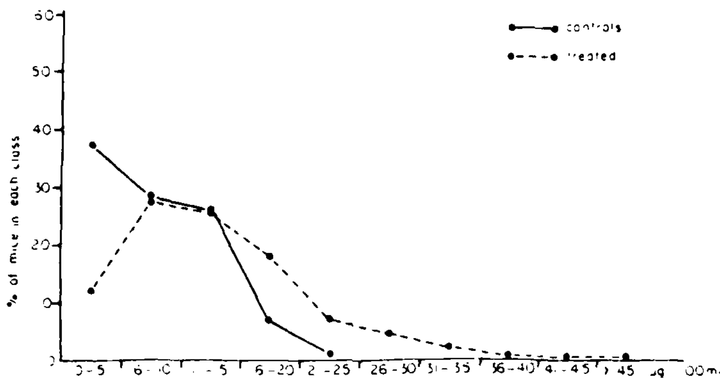

Fig. 1 - Effect of acoustic treatment on mice. Frequency polygon of corticosterone levels at 21 days (all samples pooled). Percentage of assays occuring at each level (by class of 5 µg/100 ml.

a. It can be seen that a much higher percentage (37,5) of assays are included in the low dosages class (below 5 µg/100 ml) for controls than for treated animals (12 %).

b. There are no more assay above 25 µg/100 ml for controls while treated animals are still found in the 36 - 40 µg/100 ml class.

One can therefore conclude to a real effect of noise on mice wether prestimulated or not.

III. Effect of noise

The data were grouped in three ways, to study the influence of three factors :

1. Period of pretreatment.
2. Acoustic frequency.
3. Duration of post-stimulation.

1. Period of pretreatment

We first grouped the data according to the period at which pretreatment had been given, irrespective of the sound frequency used. Fig. 2 illustrates a frequency polygon expressing the percent of total number of pups in each prestimulation category for different corticosterone levels. Three of the prestimulation categories show remarkable similarities : conception to birth, birth to 9 days, and 1st time. It is interesting to note that the 1st time group behaves like those which were pretreated before maturation of the auditory system at 9 days. Since all three groups are quite different from controls, it could be suggested that exposure to repeated sound stimulation before the onset of audition does not constitute habituation.

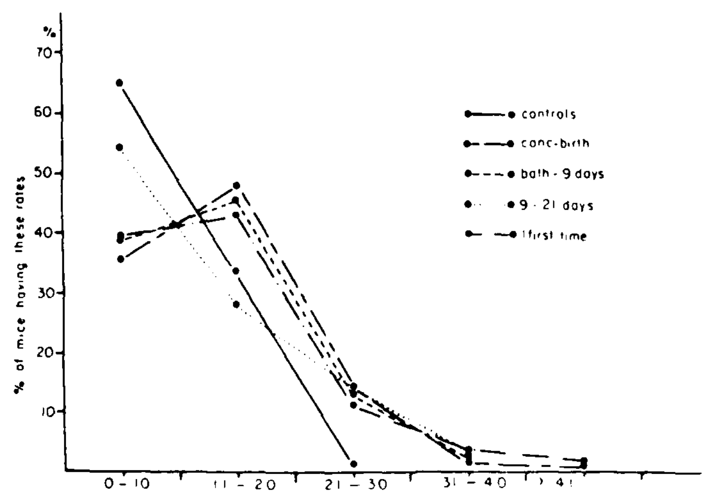

Fig. 2 - Effect of period of pretreatment of mice' response to a sound stimulus. Frequency polygon of corticosterone levels at 21 days (by classes of 10 µg/100 ml ,all frequencies polled).

The 9 to 21 days category is different from the other experimental groups for intervals of low corticosterone levels (0 - 20 µg/100 ml), and most resembles control groups. This is also illustrated with Fig. 3.

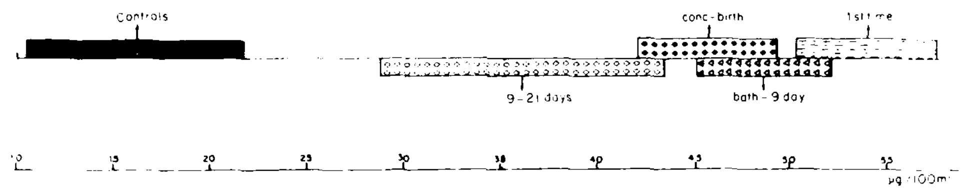

Fig. 3 - Graphic representation of the corticosterone assays according to date of pretreatment (10 kHz) are represented : mean values (↑) and confidence intervals (lengh of tracing).

It is the only group prestimulated after the onset of audition. This suggests that a certain habituation to an acoustic stimulus has indeed occurred.

2. Acoustic frequency

We report here only the results for the groups "1st time".

A study of the interaction of frequency and period of pretreatment gave results which are particularly complex and will not be reported here, being still under study.

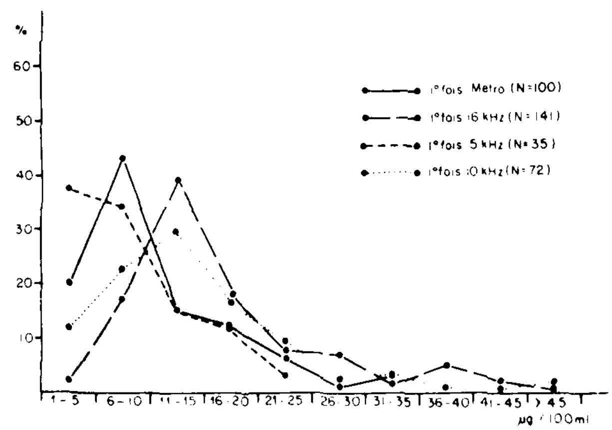

Fig. 4 - Frequency polygon expressing the percent of total number of pups in each acoustic frequency category for different corticosterone levels. "1st time" stimulation only.

a) The 10 kHz and 16 kHz categories are quite similar, and different from the other two groups in that the peak of percentage is at higher levels (32 % and 39 % respectively in the 11 - 15 μg/100 ml class).

b) Subway noise and 5 kHz, which are at the lower limits of mouse audition, show greater percentages (63 and 71,5 % respectively) of mice in the low corticosterone level intervals (1 - 10 μg/100 ml). The two stimuli are most different, however, the lowest corticosterone levels (1 - 5 μg/ml). The percentage of pups exposed to 5 kHz in that category is almost twice that of pups exposed to subway noise. Pups appear to be more stressed by frequencies which are well within the area of greatest hearing sensitivity.

3. Duration of post-stimulation

The effect of stimulus duration is considered here for one frequency (10 kHz) and for two durations :

- 1 minute of sound (So) + 10 minutes of silence (Si) (N = 121)
- 10 minutes of sound (So) + 1 minute of silence (Si) (N = 103).

Data were compiled for 5 experimented days and illustrated (Fig. 5).

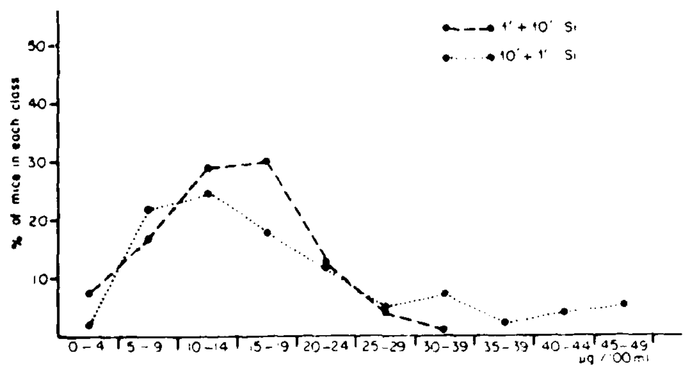

Fig. 5 - Effect of lengh of stimulus on mice response.
Frequency polygon of corticosterone levels at 21 days (by classes of 5 μg/100 ml).

The main conclusions are that :

A) For a short stimulus (1 min) the highest percentages are in the 10 - 20 classes while for a long stimulus (10 min); they are slighly lower (in the 5 to 14 classes).

B) But for the long stimulus some mice show a very high degree of stress (18,5 % mice have above 35 μg/100 ml while the shortly stimulated ones have none in these classes). Thus the duration of stimulation does not

seem to be an important factor in the stress response.

4. Other stresses

Table 1 summarizes results of one serie of tests performed in the "other stress" group.

A. All of these stresses raise the corticosterone levels. The values range from 15 to 22 µg/100 ml, but are never less than 4,5 fold higher than the control.Least stressful is separation from parents at 21 days (normal time for weanina); separation at 19 days, i.e. 2 days before normal weaning, is as stressful as most of the other procedures.

Most stressful is separation plus crowding on an icy floor, corticosteroid levels are 9 times that of controls (Table 1, sample 8 - 9).

B. The effect of noise added to these different stresses is usually negligeable if the primary test has been important. This can also be seen from Fig. 6 which represents for one group of mice some of these stresses with or without addition of an acoustic stimulus. This figure is only a graphic representation of the dispersion rates of all dosages in each category, mean values and the confidence intervals.

It can be seen here too that all stressed groups are different from controls, and that the greatest similarity is between each stress with or without added noise.

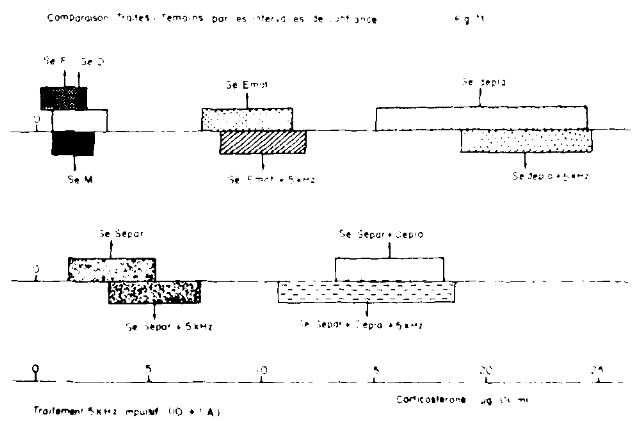

Fig. 6 - Graphic representation of the corticosterone assays, according to date of pretreatment.
Are represented : mean values (↑) and confidence interval (lengh of tracing).

C. Noise is effective as an added stimulus only on the pups separated at 21 days, therefore practically unstressed by this separation.

Therefore, when a stress has reached a certain intensity, and the corticosteroid have risen to a certain level, it will not be influenced by further manipulations. Corticosteroid dosages do not therefore seem to be a good indicator diversifying the influence of one stress rather than another in multiple stresses.

Stress applied	Dosage in µg/ml	Value of control/treated Index	Statistical Significance	
			With true control	With or without sound
1. Control	1.67	—		
2. Separated at 21 days	2.75	1.2	0.11 NS	2 } 5.17
3. Same + 5 kHz, 10 min	6.52	2.9	8.10 **	3 } *
4. Control	3.39	—	—	—
5. Separated at 19 days	15.11	4.5	40.52 ***	5 } 0.014
6. Same + 5 kHz, 10 min	15.57	4.6	43.76 ***	6 } NS
7. Control	2.38	—	—	—
8. Separated + crowded on cold floor	21.92	9.2	160.43 ***	8 } 0.12
9. Same + 5 kHz, 10 min	20.31	8.5	135.08 ***	9 } NS
10. Displaced	17.33	7.3	91.91 ***	10 } 0.14
11. Same + 5 kHz, 10 min	15.78	6.6	75.45 ***	11 } NS
12. Control	1.67	—	—	—
13. Separated + displaced	14.32	7.2	76.40 ***	13 } 1.32
14. Same + 5 kHz, 10 min	18.66	9.4	139.64 ***	14 } NS
15. Control	3.39	—	—	
16. Transfered to another cage	18.39	5.4	66.37 ***	16 } 0.41
17. Same + 5 kHz, 10 min	21.13	6.2	92.83 ***	17 } NS

Table 1 - Effect of different type of stresses on corticosterone levels of mice pups.

CONCLUSIONS

The experimental procedure related in this paper being very intricated may warrant a short summary :

Mice were prestimulated either
from conception to birth
from birth to nine days (onset of audition)
from nine days to weaning - that is during normal auditory phase.
or not prestimulated at all.

Just before blood sampling they were restimulated (or stimulated for the 1st time) at the frequency of prestimulation (5, 10 or 16 kHz or a white noise (subway).

From the three factors analysed (period of pretreatment, acoustic frequency of stimulus and duration of poststimulation), a number of conclusions can be drawn.

1. All stimulated mice have higher corticosterone levels than controls but at different levels.

If one makes a cumulative curve of corticosterone levels according to acoustic frequencies of stimulation, one finds nearest to control the 5 kHz then subway 10 and 16 kHz. This is perfectly understandable if one considers the auditory curve of the mouse,the threshold of which is still very high at 5 kHz. The subway noise being emitted at 106 dB might be perceived through low frequency vibrations of the cage. As for 10 and 16 kHz they are at the lowest threshold values.

Therefore, results as regards to frequency are those that could be expected.

2. For the period of prestimulation, on the other hand, our hypothesis had been,remembering Ando and Hattori's work on babies (1970-1977), that sound heard during the period of formation of the auditory system, might change the animals reaction to a later stimulation. This did not turn out to be true since only pups stimulated from 9 to 21 days show a certain habituation.

It must be noted that an acoustic stimulus, even of great intensity (103 to 106 dB) is less stressful than all other stresses coming from a change in the pup's environment (early separation from the mother, change of cage or of room, etc.).

Finally it must be noted that, if such clear cut results were obtained,

it was due to the high number of assays performed ; for variability is enormous, and it seems that more severe stresses bring about higher rates of variability which could not be related to any of the psychophysiological characteristics of the pups.

ACKNOWLEDGEMENTS

We want to thank Antoine Bagady for the statistical analyses and all the staff of the laboratory for their help in bringing this paper out.

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PRELIMINARY EVIDENCE ON FETAL AUDITORY HABITUATION

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INTRODUCTION

Objective behavioral and physiological reactions to auditory stimulations can be reliably measured at 28 weeks in the human fetus in utero. Mature brainstem auditory evoked potential threshold are recorded as soon as 35 weeks in the premature newborn (UZIEL et al. 1980).

The fetus is constantly exposed to noise of maternal origin and, eventhough developing in a quite protected acoustical environment, is subjected to a relative amount of external sound stimulations, these being mostly composed of low frequencies, under 1500 Hz. The higher the frequency, the higher the attenuation, e.g., the latter is only of 2 dB at 250 Hz but increases to 20 dB at 1000 Hz (QUERLEU et al. 1981).

Several animal and human experiments have demonstrated that some of these prenatal auditory stimulations may have an effect on the developing fetus. Depending on their physical structure and on exposure conditions, they may lead to acoustical trauma of the cochlea, participate in the specification of the functionnal properties of the auditory system and, as we will see, may also be involved in the sensory organisation of the futur infant as well as in very precocious learning processes (GRANIER-DEFERRE and BUSNEL, 1981).

It has been shown that newborns, whose mothers have been almost continuously subjected to a prolonged and intense low frequency noise (aircraft noise), are adapted to this same noise and that the degree of

this adaptation is function of the period and duration of the prenatal exposure (ANDO and HATTORI, 1970, 1977). But these extreme conditions are rarely encountered and impossible to study with proper control in human subjects. On the other hand, it is most frequent that mothers are, now and then, and for a limited period of time, exposed to repeated loud external noises and it is thus worth considering how the fetus reacts and examine the characteristics of his successive responses independenlty of the mothers physiological reaction.

Habituation is the progressive response decrement to a repetitive and non-significant stimulation, that can be distinguished from sensory adaptation and neural refractoriness. Usually, it is considered to be obtained when the organism stops reponding after a number of successive trials; reactivity is recovered after a variable amount of time (HEBB, 1958; THORPE, 1963; KANDEL, 1979). Habituation is one of the most elementary form of learning and is most likely to give us insight into the auditory learning capacities of the fetus.

The typical fetal response to a loud and sudden external sound stimuli includes a short latency heart rate acceleration (averaging 15 beats per minute(bpm)), usually accompanied (85% of the cases) by limb movements or change in position (BUSNEL and GRANIER-DEFERRE, 1982). It appears that most reactions analyzed in the litterature may be interpreted as startle responses, characteristic of a defensive reaction, and it is known, from newborn and infant studies, that auditory habituation is rather difficult to induce in this case. On the contrary, an orienting response, which is charaterized by heart rate deceleration, habituates and shows an extinction quite rapidly (GRAHAM et al. 1968, GRAHAM, 1971).

A first experiment has thus been designed to find an auditory stimulation that would elicit orienting responses, mostly using low level rythmic pure tones, so as to perform a comparative study on fetal habituation (COHEN,1983). As up to know, no reliable data has been found, only preliminary results on fetal cardiac and motor reactions to a repeated intense and sudden broadband noise will be exposed.

Few studies have been performed in this field; some authors have briefly reported an unresponsiveness or a modification in the nature of the response after repeating the sound stimulus (FLEISHER,1955 ; DWORNICKA et al, 1963; BENCH et al ,1967; GOODLIN et SCHMIDT, 1972), others have exten-

sively studied the fetal motor response habituation to a vibratory stimuli, directly applied on the maternal abdominal wall(GOUPIL et al,1976; LEADER et al,1982 a-b), or the fetal heart rate (F.H.R.) decrement to a loud tone (2000 Hz, 120 dB) (GOODLIN et LOWE, 1974), but no systematic experimental work have been performed on motor and F.H.R. modification and on their interaction, using auditory stimulations exempt from vibratory components with a strict control of the mothers physiological reactions (i.e., preventing her from hearing and being aware of the moment of emission of the stimuli).

This lack of data is easily explained when considering the variou problems inherent to studies involving the fetus in the uterus. One major point is the difficulty to identify the different successive fetal state of alertness. They also change rapidly, according to a cycle of 60/90 minutes(TIMOR-TRITSCH et al, 1978; VAN GEIJN et al,1980; VISSER et al, 1982) and the duration of each state is short, between 3 and 20 minutes (NIJHUIS et al,1982). Therefore, it is very difficult to stimulate the fetus with a sufficient number of stimuli during the same state of alertness, which is highly preferable, as it has been shown, in the newborn and the young infant, that reactivity to a stimulus, habituation and state of alertness are not independant factors(GRAHAM et al 1968;GRAHAM, 1971; TAYLOR and MENCHER, 1972; HUTT et al, 1973; NELSON et al 1976; MOREAU,1976). Consequently, fetal reactivity might change before habituation is established, either being enhanced (i.e., when the fetus changes from sleep to quiet wakefulness)or reduced (unresponsiveness may be observed in some sleep state (PRECHTL,1974-1982)).

Furthermore, only two quantitative parameters can be examined and the technology involved in both cases are still not completely satisfactory. Recording F.H.R. with a Doppler ultrasound transducer is unprecise, with still frequent signal loss, especially during bursts of motor activities. Real time ultrasound scanner allows only observation of a restricted part of the fetal body. As it is necessary to follow its displacement to estimate the magnitude of the motor reaction, and also because it is difficult to shift rapidly from one area to another, a preliminary choice must be made. This choice is always limiting, the best area to examine a startle response is not what should be preferentially looked upon to discriminate fetal alertness.

MATERIAL AND METHODS

1) <u>Subjects</u>

Records were made from 14 healthy (non medicating) volunteer mothers, between 37 and 39 weeks of gestation. Procedure was first described, and a questionnaire was used to assess fetal external sound environment and any factors that might eventually affect his reactivity during the test session.

2) <u>Acoustic stimulation</u>

The stimulus, a 5sec pink noise, low-pass filtered at 800Hz to eliminate any vibratory component, was delivered, after amplification at 106 dB S.P.L. (re:20 uPa) through a loudspeaker, 20 cm above the maternal abdominal wall, in front of fetal head.
According to the acoustic transfert function that has been computed from recordings inside the amniotic fluid (QUERLEU et al,1981), this stimulation can be estimated to have an intensity range of 70-86 dB inside the uterus.

3) <u>Procedure</u>

Mothers were lying on a reclining chair, wearing earphones delivering a relatively monotonous musical sequence, mostly composed of series of classical guitar arpeggios, chosen to mask part of the fetal stimulation. Masking was completed by covering the loudspeaker with a thick blanket falling around the mothers body.
Stimuli were delivered during the same state of alertness, only during periods of no fetal movement, when F.H.R. maintened a low oscillation, regular baseline for at least 60sec. Interstimulus intervals were thus variable.
F.H.R. was recorded by means of a wide-range Doppler ultrasound transducer (Hewlett-Packard) and lower limb movements visualized with a real time ultrasound scanner (C.G.R. - Roche) connected to a video system (Sony AVC60 recorder). F.H.R. and movement recordings were synchronized with a tonal event marker.
The data (F.H.R. and sound stimulations) were kept on a multi-channel tape recorder (E.P.I.2) and beat to beat (R-R intervals) heart periods computarized and analyzed on a micro-computer (Minc 11-23).

Each 60sec interval, just before stimulation, constituted the control period (prestimulus H.R.) for each period of stimulation. F.H.R. data during trials were analyzed according to 6 parameters, one constituting a magnitude score: peak amplitude (value of the F.H.R. acceleration from prestimulus level); others,time measurements: reactivity latency (as the value of the standard deviation of the mean of the control period), peak latency, initial duration (first component of the response, before return to prestimulus value), total duration (this parameter includes the latecomponents of the heart response) and the response surface (computed from initial duration) which integrates both magnitude and time variables.

Video recordings of fetal limb movements were analyzed image per image (Grundig BK401), reactivity latency was measured with an image incorporated digital chronometer (50ms accuracy),automatically triggered by the

sound stimulus transient.

RESULTS

Because of state change, it was not possible to test all subjects with tne same amount of stimulations (n=3 to 10 stimuli per subject). Modification of state of alertness occured after a different number of trials. Some subjects entered long periods of spontaneous movements either on early or late trials which resulted in very long inter-stimulus intervals. Therefore, to analyze comparable data, the results on the three first stimuli, all given with an inter-stimulus interval of no more than three minutes each (between 1 and 3 mn) on 12 mothers have been considered.

Response decrement was observed between the first trial and the following ones.

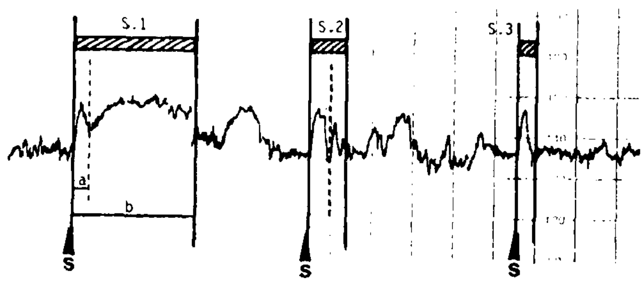
1) F.H.R. response

Peak amplitude, response surface and total duration decreased significantly from the first to the third trial (table 1). Total duration was the only parameter demonstrating a clear decrement on second stimulation and seems to be the variable most affected by stimulus repetition (fig.1).

	S1	S2	S3	mann-whitney U test
Peak Amplitude (bpm)	25.6	20.5	15.9	S1-S3: U=22.5 P<.05
Initial Duration (sec.)	25	19.7	17.9	n.s.
Total Duration (sec.)	72	36	21	S1-S2: U=25.5 P<.01 S2-S3: U=22.5 P<.01 S1-S3: U=8 P<.001
Reactivity Latency (sec.)	3.6	2.8	3.1	n.s.
Peak Latency (sec.)	11.2	11.7	11.4	n.s.
Response Surface (bpm x msec.)	376	160	104	S1-S3: U=18 P<.05

Table 1: Median values of the different F.H.R. parameters during the first (S1) and subsequent stimulations (S2 and S3).

On the contrary, the duration of the first component of the response (initial duration), which represents the cardiac primary response, is not significantly altered, eventhough a slight reduction is observed between trials. Difference in total duration is easily explained as it also includes the cardiac components of fetal movements and thus also evidences the strenght or/and the duration of the simultaneous motor reaction. Therefore, these late components tend to disappear by the third trial, while the cardiac primary response remains almost unchanged. It seems that the latter is in most cases the only apparent component observed on the third trial: initial duration and total duration have then equivalent values and 85% of the time no motor reaction or weak reactions have been recorded.



S : Stimulation   a: initial response
b: total response

Figure 1: Example of evolution of initial and total responses during a three stimulation period.

The statistically significant decrement of surface response, intégrating both peak and time variable is less important than expected as surface has been computed from initial duration.

No significant changes have been observed on both latencies. Higher numbers of stimulations are probably necessary to influence these two parameters.

2) Movement response

Video tape analysis show that number and strenght of motor responses decrease significantly with repetition of sound stimulation. From S1 to S3: there is an increasing amount of no-responses (all fetus respon-

ded on first stimulation, 78% on S2 an 64% on S3) the number of strong responses diminishing parallely (64% in S1, only 14% on S3),(between S1, S2 and S3: $X^2=8{,}34$, df=4, P .15, between S1 and S3: $X^2=9{,}43$, df=4, P .05, cf figure: 2)

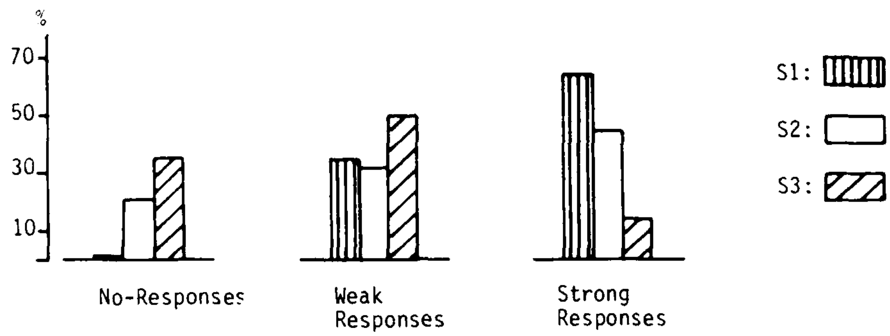


Figure 2: Proportions of movements according to their strength for each stimulation.

Motor responses start with shorter latencies than cardiac responses (median=1.33 sec. instead of 3.2 sec.). This latency tends to increase from first to subsequent trials (S1=1.1 sec., S3=2 sec.) and weak movements have longer latencies (2 sec.) than strong movements (1 sec.)

CONCLUSIONS

Fetal reactions to an external sound stimulation decrease with repetition of this stimulation when emitted at short intervals of time. Magnitude of the cardiac response, a heart rate acceleration, appreciated with various parameters (peak amplitude, response surface, and total duration) is significantly reduced from first to third presentation of a 106 dB pink noise of 5 sec. duration. Sudden extension of the lower limb, a motor response frequently associated with FHR acceleration, exhibits a concomitant decrease in the number of its occurence and in its strenght. Such a quick decrement of the response patterns to a sudden noise suggest that, as newborns, fetus may cease to respond to this noise through habituation as preliminary studies assumed.

Near term fetuses seem less likely to continue to display motor responses to our acoustic stimulation, than to the vibro-tactile stimulation delivered by LEADER et al.(1982), to which "no patients habituated

in less than ten stimuli". This vibratory stimulation -its auditory components included- may induce a stronger, or a different, reaction than a simple auditory stimulation. It is difficult to make further clear statements on this point because, while LEADER et al. looked at chest and upper limbs of the fetus, we choosed to examine the extention of the leg as it is a major component of both the startle resonse, and of the newborn Moro reflex. Recent work (DeVRIES et al., 1982) showed that this movement is the first perceptible during fetal behavior ontogenesis.

FHR responses of some of the observed fetuces displayed a qualitative modification over stimulation. Figure: 3 shows that the accelerative response to the first stimulation became biphasic, with an accelerative and a decelerative components after stimulation 2 and 3. This may reflect a change in neuro-vegetative reaction to the sound, another index of beginning of habituation.

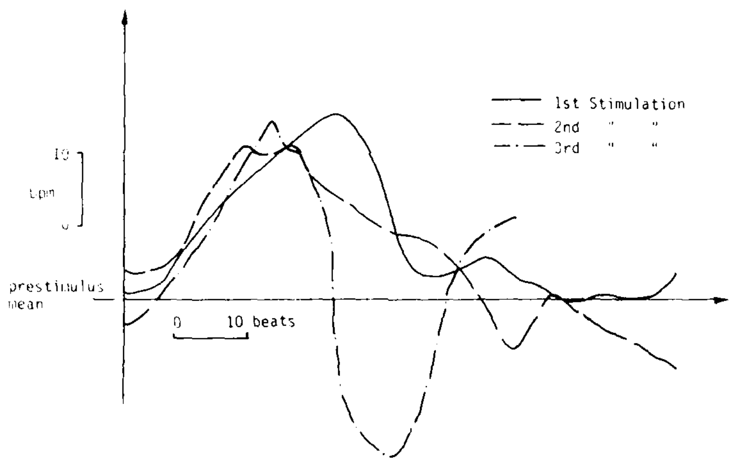


Figure 3: Progressive appearance of a biphasic pattern of FHR response.

Fetuses tested in this preliminary study received their three stimulations during the same state of alertness, usually 2F as defined by NIJHUIS et al. (1982). Exposure to greater series of stimulation takes long period of time, during which one or several changes of state of alertness might occur. Figure 4. shows that a sound stimulation (100 dB, 5 sec.) producing a clear FHR acceleration when administered during a

state of relatively high H.R. variability may become suddenly ineffective, a few minutes later, in a low H.R. variability state. Such an effect, which is not due to habituation may interfere with its establishment, as it does in the newborn (NELSON et al., 1976).

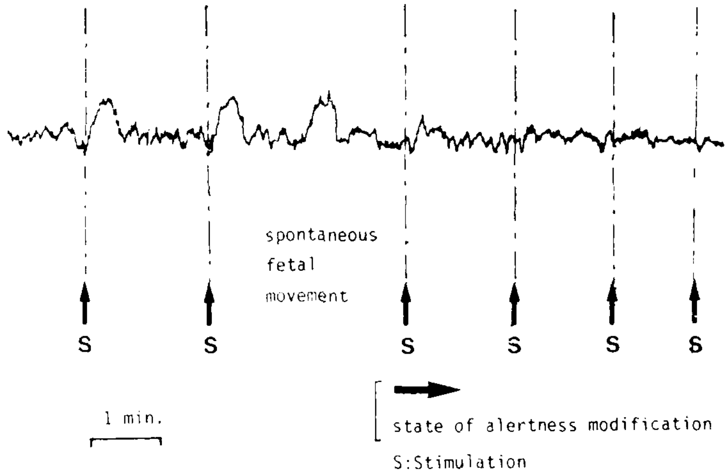


Figure 4: Reduction of F.H.R. response after change of state of alertness (evidenced by a change in F.H.R. variability).

Demonstration of prenatal auditory habituation is of special interest as it brings evidence on fetal learning capacities in the acoustic field. It has been frequently suggested, and several experiments are presently being conducted in attempt to demonstrate this hypothesis, that during the last part of fetal life learning of the mother's voice characteristics might take place. This learning, which may be established from an auditory imprinting (LECANUET, 1983) could contribute to the development of preference for this particular voice, and may play a part in the emergence of primary attachments.

Aknowledgements: We wish to thank Prof C. SUREAU, the staff of Baudelocque maternity and the mothers who have participated in the study. We are also grateful to Mr R. LE HOUEZEC for his unevaluable technical assistance.

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EFFECTS OF IMPULSE NOISE ON VISUAL EVOKED POTENTIAL AND CHOICE REACTION TIME PERFORMANCE

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INTRODUCTION

Because in this report we evaluate the effects of noise on human well-being, at least two facts must be taken into account. Firstly, the effects of noise depend on the type of noise exposure (continuous, steady-state, impulsive, impact, etc.), on the level and the duration of exposure, and on the individual's physical and psychological health status. Secondly, the results of studies on noise have not been uniform.

At present it is not definitely known whether there is any other disease directly related to noise exposure besides noise-induced hearing loss (Jansen, 1980). However, it is known that noise can have harmful effects on the functions of the human body (McLean & al. 1977; Cohen & al. 1981; Malchaire & al. 1979), and mind (Jenkins & al. 1981) even after the noise exposure has ceased (Glass & al. 1972).

Some studies showed that noise may act not only as a neurobehavioral arouser but also as a neurobehavioral distractor

(Loveless, 1976; Smith & al. 1973). The processing of a motor response to a stimulus is also affected by noise. Noise can either promote or debilitate reaction time (RT) performance (Roth & al. 1976; Broadbent, 1979; Hartley, 1973).

The extra-aural effects of noise include arousal and activation reactions (Loveless, 1976). These reactions are related to the excitability reactions of the brain. Arousal is said to occur when a change in input produces measurable incrementing of a physiological (e.g., SCR, EEG) or behavioral indicator (e.g., RT) over a certain baseline. Arousal is a phasic reaction to input. It can include a sudden change in intensity to which the organism is unaccustomed. Activation is a tonic readiness related to the response mechanisms (Pribram & al. 1975). When the individual's state of activation and vigilance is high RT can decrease (Zenhauser & al. 1974; Trumbo & al. 1975) or the evoked potential can enhance (Haider & al. 1968; Courchesne & al. 1975).

The purpose of this study was to compare the arousal and activation effects of two levels of impulse noise on visual information processing as reflected by the visual evoked potential and on the motor response time to a visual stimulus. It was expected that repetitively arousing stimuli such as abrupt and loud impulse noise would increase the activation level of the organism and modify the stimulus-response mechanisms differently from weak impulse noise and noiseless control conditions.

MATERIAL AND METHODS

Subjects

Seven healthy male students (mean age 23.3 yrs, SD 2.06) from a technical university participated in the experiment. They were paid for their participation. All the subjects (Ss) had some earlier experiences with occupational noise connected with their subject of study (mining engineer, road building technology, etc.).

Noise exposure

The noise exposure was constructed to simulate the noise of a shipyard. It comprised pink background noise and artificially generated bursts of impulse noise. The background noise was continuous. The bursts of impulse noise (a square wave of 200 Hz, rise time 1.25 ms, peak duration 50 ms and 9 Vvp with a wave of 450 ms and 0.4 Vpp) were inserted into the background noise. The rate of impulses was one per second, randomly. The noise was broadcast via an amplifier (Yamaha CA 1010) and two loudspeakers (Yamaha) into the air of the test room. The loudspeakers were placed diagonally toward the subject 1 meter behind his ears.

There were two levels of noise exposure: a lower level of exposure and a higher one. The lower level was called weak noise. The background noise was 60 dB(A) and the burst of impulse noise 75 dB(A). The higher level, called loud noise, had a background noise of 75 dB and bursts of impulse noise of 90 dB. The experiment consisted of several noise blocks. A block contained 295-298 bursts of impulse noise. However, in one block, the background noise was replaced by noise generated from pneumatic chiselling. This noise was played for 2 min of every 10 min period. The intensity was the same as that of the impulse noise burst in both noise levels.

Recording system

The EEG was recorded (Siemens-Elema Mingograf 10) with cup silver chloride-silver electrodes (Siemens-Elema) from vertex (Cz), frontal (Fz), and parietal (Pz) positions. Electrodes attached to each ear lobe were linked for reference. Siemens-Elema electrodes were taped to the infra-orbital and supra-orbital ridges of the left eye to measure the vertical eye movements. A Siemens-Elema electrode served as the ground and was taped to the right mastoid. After amplification (time constant 10 sec) the EEG and RTs were stored on a disk for further analysis. The sampling rate of EEG was 3 msec over the 768 msec period of analysis, starting 60 msec before the stimulus onset. The baseline was determined as the mean amplitude over the prestimulus period of 60 msec and referred to the zero level of the AD-converter.

Procedure

The subjects sat at a test table in a comfortable chair. In front of them at a distance of 215 cm there was a panel with three stimulus lights (Ø 15 mm, 7xESBR 5531 red leds, 30

mmcd) placed 12 cm horizontally apart from each other and at the subjects' eye level. The lights were randomly lit once every 2, 4, or 6 sec (ISI). The subjects' task was to attend the illumination of the lights and to put out either the left or the right side lamp as quickly as possible by pressing a microswitch on the test table with the index finger of the preferred hand. These lights were called the RT lights. When the middle lamp was lit, the subjects had to withhold their response. This light was called the No-RT light. The lights were lit 200 times per block of which the middle light was lit 20 times randomly. The duration of a block was 13 min 20 sec.

The subjects always started the session with a control block done in silence. Then they proceeded to a session of six blocks in noise exposure, immediately after which they had an extra block which was called the after noise block. On the first day in the morning and in the afternoon, the subjects had a session in weak noise exposure. On the second day they had a similar session in loud noise exposure. There was a 90 min. lunch break between the morning and afternoon sessions.

The EEG signals were averaged separately for the RT lights and for the No-RT lights at each electrode position over the sessions, for the subjects in weak and loud noise exposure, and for the control and after noise blocks. The RTs for the left and the right light were analyzed together to show the mean RT separately for weak and loud noise exposure, for the control blocks, and for the after noise blocks. Prior to storage of the EEG signals, an EOG detector cancelled the EEG of a trial whenever the EOG exceeded $\pm$ 45 μV on each channel.

RESULTS

Reaction time (RT)

Figure 1 shows the mean RTs for the various conditions. The F-test revealed that the RT differed significantly between the conditions ($p<.01$). The Newman-Keuls multiple comparisons showed that the RTs were the shortest in the loud noise exposure and after it and the longest in the weak noise exposure and after it ($p<.01$).

Errors

On average, the subjects responded to the No-RT light most often in the control condition and in loud noise exposure

Fig. 1 - Mean reaction time in the control condition (silence), in weak and loud impulse noise, and after both types of noise in the after-effect conditions. The average number of reactions was 5,222.

than in the other conditions. The least response errors were made in the block after weak noise exposure (F-test, $p<.05$). Other errors, e.g., anticipated (shorter than 100 ms) or missed (longer than 600 msec) reactions were made by the subjects most in weak noise exposure and least in the control condition and after loud noise exposure but these differences were not significant.

Evoked potential (EP)

The first most positive deflection from the onset of stimulus was designated to be P1, and the first most nega-

tive deflection was designated to be N1. P1 was detected, on average, between 115 and 132 msec, N1 between 157-172 msec. P2, N2, and P3 were designated to be the next most positive and negative deflections. P2 was found between 238-255 msec, N2 between 309-322 msec, and P3 between 382-395 msec. After P3, two other amplitude measures were taken: first, the maximum amplitude between 490-540 msec, and second, the maximum amplitude between 540-590 msec from the onset of stimulus. All the amplitude measures were referred to the baseline. Only the frontal EPs at Fz are reported here.

In general, in every condition the potentials evoked by the RT lights and by the No-RT light differed from each other. The potential evoked by the No-RT light had a large slow positive deflection when compared with the potential evoked by the RT light. This slow positivity started already by P1, continued over the whole period of analysis, and was most prominent by P3 and by the latencies of 490-540 msec and 540-590 msec. Only N2 reached negativity in the block after loud noise exposure. Otherwise N1 and N2 remained positive in relation to the baseline. P1 and P3 to the No-RT light were twice as positive as P1 and P3 to the RT lights.

Evoked potential (EP) to RT lights

Figure 2 shows the EP averaged for the RT light. The Anova2 showed that the EPs between the conditions differed significantly ($p<.01$). There was also a significant interaction between the EPs and the conditions ($p<.01$).

msec, and 2) by the latency of 540-590 msec were slightly negative in the control condition, the most negative in weak and loud noise exposure, but positive after both noise conditions (p<.01).

Evoked potential (EP) to the No-RT light

Figure 3 shows the EP averaged for the No-RT light. The Anova2 demostrated that the EPs between the conditions differed significantly (p<.01), but there was no significant interaction between the EPs and the conditions. The F-test revealed that none of the EP deflections (P1, N1, P2 or P3) differed significantly between the conditions. Only the maximum peak amplitude by the latency of 540-590 msec tended to differ between the conditions (p<.05). The Newman-Keuls multiple comparisons showed no significant differences between the conditions.

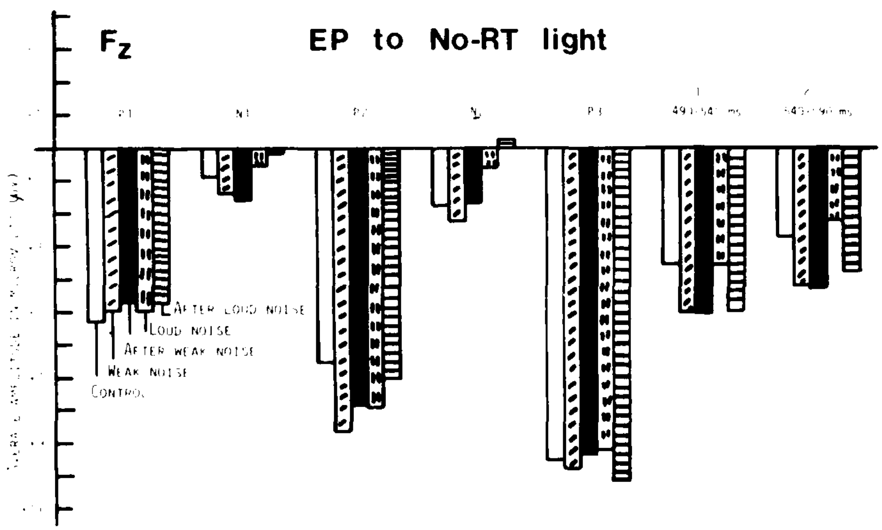

Fig. 3 - Histogram of the EP averaged for the No-reaction time light at Fz in the control condition, in weak and loud impulse noise, and after both kinds of noise in the after-effect conditions. The number of averages varied between 188 and 661 and are from 7 subjects.

The Newman-Keuls multiple comparisons revealed that P1 and P2 were the most attenuated in the block after loud noise exposure ($p<.01$). N1 was the most enhanced in the block after loud noise exposure ($p<.01$). N2 was positive and crossed the baseline in none of the conditions. However, the least positive N2 occurred in loud noise exposure and after it ($p<.01$). P3 was the most attenuated in both weak and loud noise and nearly equally large in every noiseless condition, i.e., the control condition and in the blocks after weak and loud noise exposure ($p<.01$).

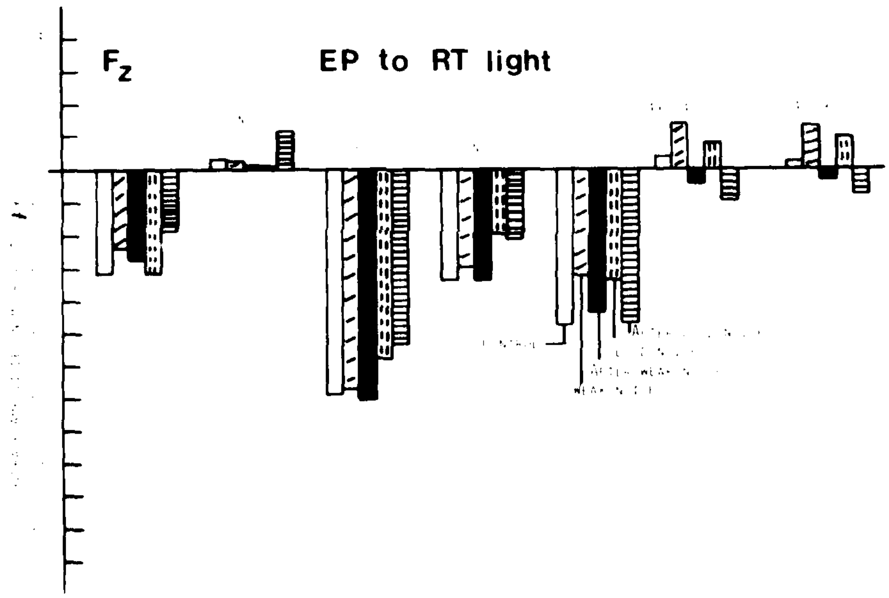

Fig. 2 - Histogram of the EP averaged for the reaction time lights at Fz in the control condition, in weak and loud impulse noise, and after both kinds of noise in the after-effect conditions. The number of averages varied between 2,193 and 8,113 and are from seven subjects.

The maximal peak amplitudes 1) by the latency of 490-540

Correlation between EP and RT

A significant negative correlation was found between the RT and P3 at Pz only in the noise conditions (weak noise: $p<.01$, $r=-.73$, df 43; loud noise: $p<.01$, $r=-.65$, df 41).

DISCUSSION

The RT results showed that loud noise speeded the reaction to the light stimulus whereas weak noise slowed it down. Zenhausern et al. (1974) reported that only the highest level of white noise accessory stimulation (70 dB) lowered RT. Kohfeld et al. (1978) reported that background noise debilitated RT when the noise was too loud or if the noise was of moderate intensity but temporally unpredictable. The most errors in responding to the No-RT light were made in the control and the loud noise conditions, whereas anticipated and missed reactions occurred mostly in weak noise. RT and P3 of the EP correlated negatively but only in noise exposure. Gulian (1971) found that RT and autonomic activity (GSR) also correlated only in noise exposure.

The RT data lead to the conclusion that loud impulse noise increased both the arousal and activation levels of the organism when measured by RT performance. Loud impulse noise acted as a behavioral arouser that caused faster vigilance performance than weak impulse noise, which had the opposite effect on RT and slowed down vigilance performance.

The results of EPs at Fz showed that the only EPs affected by noise exposure were those to the light stimulus to which the subjects had to react with a motor response. Weak noise had no clear effects on the EP components except P3 and the potential after it. When compared with the effects of loud noise on the EP components, it can be seen that P1-N1 showed no such systematic effect of noise as the P2-N2 complex or P3 and the peak potentials (1 and 2) after P3. These differences in the effects of noise may indicate that there were at least three phases of stimulus-response processing reflected in the EP (see Frowein et al. 1981)each of which reflected the noise

effects differently. P1 was the most attenuated and N1 was the most enhanced after exposure to loud noise. The P2-N2 complex was the least positive in loud noise and after it whereas P3 was the most attenuated in both noise conditions. The peak amplitudes by 1 and 2 were the most negative in both noise exposures and the most positive after them.

A clear increase in negativity or a decrease in positivity was seen here not only by the P2-N2 complex in loud noise and after it but also by P3 in weak and loud noise. However, an increase in negativity can be seen most prominently in the peak amplitudes measured by 1 and 2 both in weak and loud noise. This negativity after P3 was similar to a CNV type of negative deflection (Walter et al. 1967). There are many studies which have shown that the negativity of the frontal EP increased during an active processing on the task-related stimulus (see Frowein et al. 1981, Näätänen, 1982).

The reduction of positivity by the P2-N2 complex in loud noise exposure and after it could have resulted from two factors. Either it resulted from "a true distracting effect" of loud noise or it reflected an increase in negativity which was superimposed on the complex that reduced its positivity. However, in both cases the positivity by N2 should have decreased. This was what happened, but not to the extent that N2 was enhanced to be negative. N1 has been proposed to reflect stimulus-related processes whereas N2 has been related to response selection. Many studies where the response to a stimulus has been silent counting or a motor reaction have found the P2-N2 complex and P3 in the EP whereas these EP components have not been found in the EP to the physically similar stimulus with no such responses (Näätänen, 1982). In the present study these EP components seemed to be most sensitive to noise effects.

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ACKNOWLEDGEMENTS

This study was financed by the Labour Protection Foundation. The author expresses sincere gratitude to the Foundation and also to the technical personnel of the Institute of Occupational Health for the instrumentation.

EFFECTS OF INDUSTRIAL ULTRASONIC NOISE IN PLASMA GLUCOSE AND FATTY ACIDS LEVELS.

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INTRODUCTION

Several studies indicate that prolonged influence of industrial noise might lead to neurovegetative reactions of the body.

During examinations on the harmful influence of the noise mechanism it was found that short term exposition caused typical stress reactions, including glucose and free fatty acid levels increase / 5 /. The reaction stops when the noise breaks off. During long lasting expositions the glucose level doesn't change / 3 / but the level of cholestrol and its esters / 6, 7 / as well as levels of total and free fatty acids increase.

In literature, we can find however / 2, 4 / that high frequency noise /10-20 kHz/ causes body homeostase disturbances with a tendency to permanent hipoglicaemia. Asbel and Gierasimowa found in their research a complex of syndroms-fatique, headache, nausea, vomiting etc. and a tendency to an incorrect glucose curve in persons persistently exposed to ultrasonics noise. Acton / 1 / suggested that the symptoms were dependend on high levels of high frequency audible sound rather than ultrasonic frequencies.

Because high frequency noise is expanding in the industry, it seems important to try to study the mechanism of these changes.

MATERIAL AND METHODS

Research on glucose and fatty acids level was carried out on 93 workers. 66 persons worked as operators of such technological industrial equipment as washers manufactured by Technochem and Strunk /36 women and 30 men, age 21-61, mean 33 yrs/. These washers produce acoustic field with intensity of 95-111 dB in the middle frequencies of 10 and 20 kHz. There were 27 non-exposed persons in the control group /age 23-59, mean 35 yrs/.

All of the persons were examined by physicians. The ekg and audiometric results were the same as for the control group.

All of those persons worked with not very big physical load during the first shift. At 8 a.m. and 11 a.m. they had a standard breakfast, specially nourishing and of caloric value- 400 and 300 Kcal. Blood samples for biochemical examinations were taken three times a shift - at 10 a.m., 1 p.m. and 3 p.m. from the ulnar vein. The research was carried out on the same persons three times a year.

Animals /white rats/ have been exposed to ultrasonic noise emitted by industrial washers 3 hours daily during 6 weeks. Peak values of acoustic pressure levels for bands of 10 and 20 kHz were 122-125 dB. The contents of glucose, fatty acids in plasma, glycogen in the liver. adrenaline, noradrenaline, 17-OHCS in urine, adrenaline, noradrenaline in adrenals and noradrenaline in the brain were determined after 1, 3, 6, 18 and 36 days of exposure. In each of the groups were 10 animals. The glucose was determined by the o-toluidyne method, total fatty acids by the hydroxsane methods, free fatty acids- the Duncome methods, adrenalin and noradrenaline by the Carlson method.

RESULTS

It was found /Fig. 1/ that the glucose level in exposed workers was the same as of the control group /Fig. 1/. Dynamics of changes during the working day were similar, too.

The contents of total fatty acids in exposed group was slightly lower than 10% than of the control group /Fig. 2/.

A statistically significant decreaase of the level of free fatty acids was stated in the exposed workers /Fig. 3/.

Big age differences of workers could have essential significance on the fatty acids levels formation, an analysis of the correlation between age and levels of the metabolits was carried out on the control and exposed group. /Tab. 1/.

It was found that glucose and free fatty acids levels depended on age in the same degree in the exposed and in the control group but compared with the control group, in the exposed workers no changes connected with the age in the total fatty acids level have been found.

Tab.1. Correlations between ages of workers and levels of the metabolits.

Metabolits	Control Group n= 27			Exposure Group n= 66	
	Blood Taken	Coefficient of Correlation	P	Coefficient of Correlation	P
Glucose	10.00 13.00 15.00	0,441 0,317 0,017	<0,05 >0,05 >0,05	0,465 0,265 0,122	<0,01 >0,05 >0,05
Free fatty acids	10.00 13.00 15.00	-0,446 -0,348 -0,206	<0,05 >0,05 >0,05	-0,413 -0,310 -0,277	<0,01 <0,01 >0,05
Total fatty acids	10.00 13.00 15.00	0,639 0,482 0,459	<0,01 <0,05 <0,05	0,122 0,065 0,149	>0,05 >0,05 >0,05

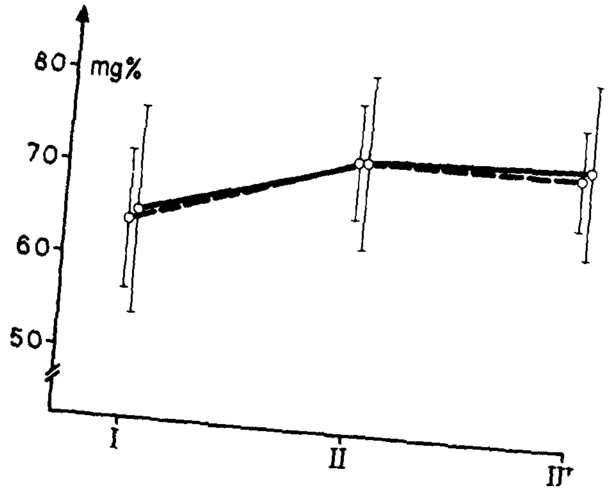

Fig. 1. Level of glucose in the plasma workers
uninterrupted line - control goup
interrupted line - exposed group

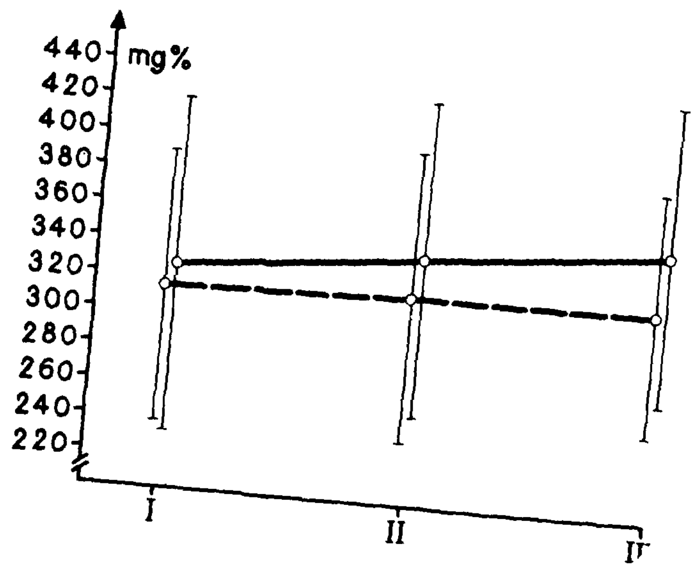

Fig. 2. Level of total fatty acids in the plasma workers
uninterrupted line - control group
interrupted line - exposed group

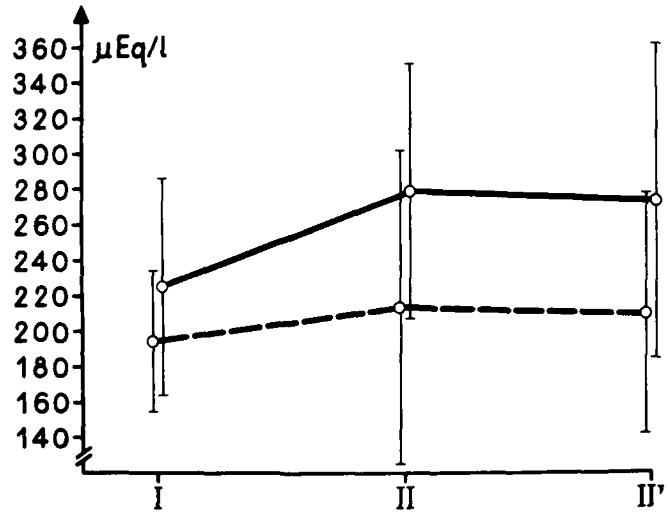

Fig. 3. Level of free fatty acids in the plasma workers
uninterrupted line - control group
interrupted line - exposed group

All the research results on animals are given in percentage of control group values. /Fig. 4, 5, 6, 7, 8/.

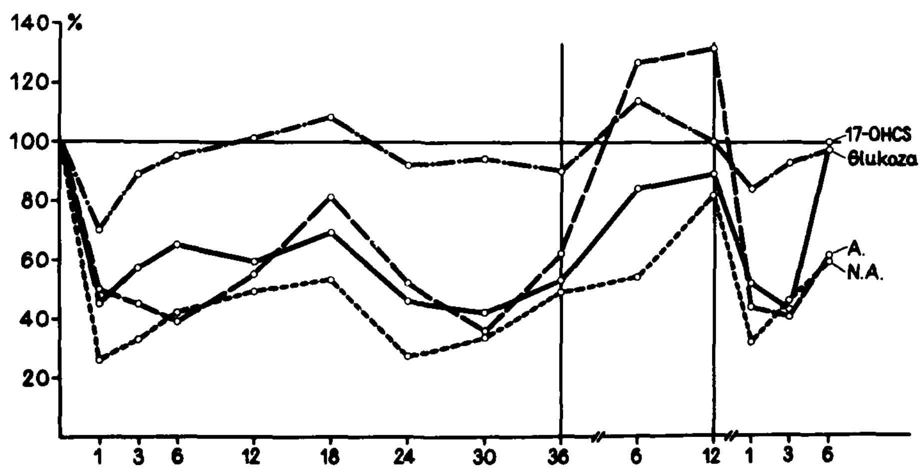

Fig. 4. Levels of glucose in plasma, adrenaline, noradrenaline 17-OHCS in urine of animals during 6 week exposition

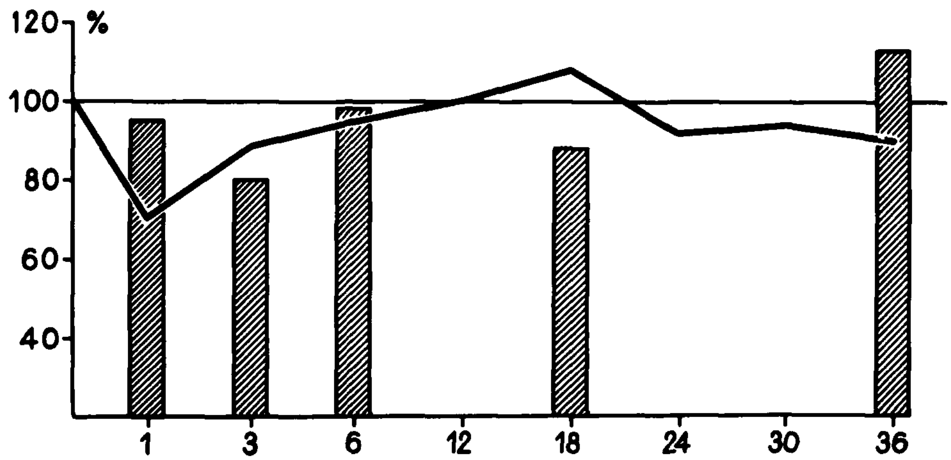

Fig. 5. Levels of glucose in plasma /uninterrupted line/ and glycogen in the liver /shaded column/ of animals.

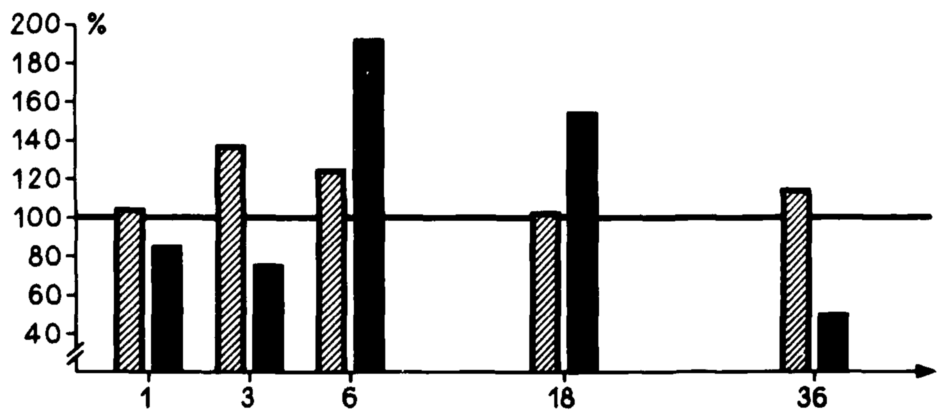

Fig. 6. Levels of free fatty acids /shaded column/ and total fatty acids /dark column/ in plasma of animals.

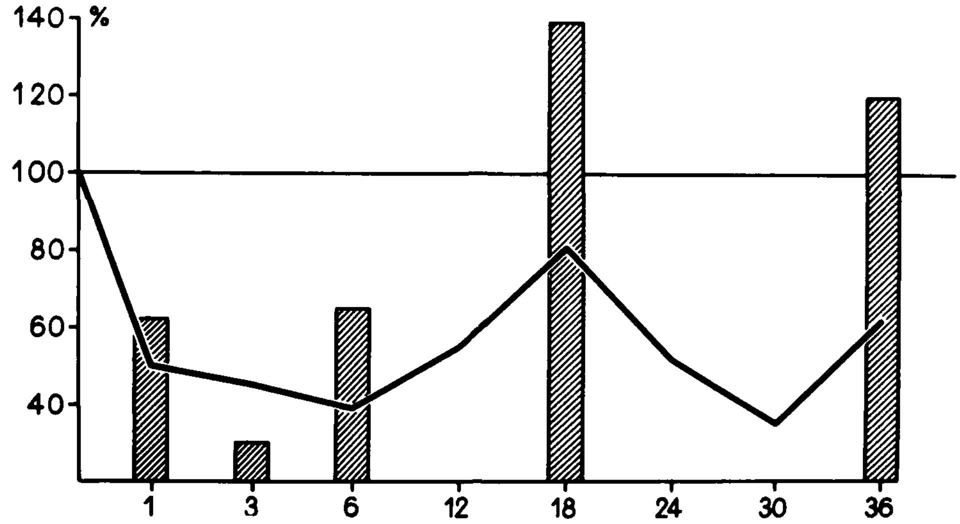

Fig. 7. Levels of adrenaline in urine /line/ and in adrenals /shaded column/ of animals.

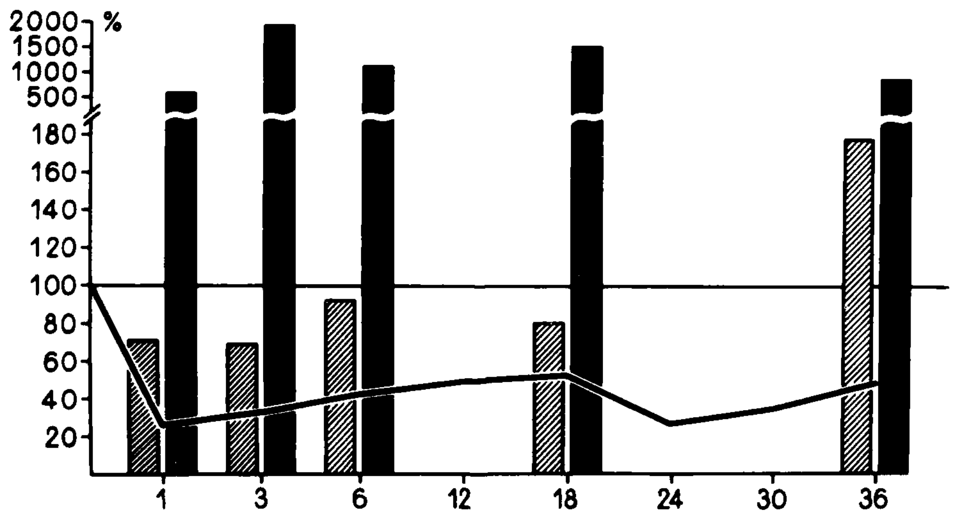

Fig. 8. Levels of noradrenaline in urine /line/ in adrenals /darc column/, and in the brain /shaded column/ of animals.

CONCLUSIONS

These results did not show any changes in glucose level of the exposed persons under prolonged influence of ultrasonic noise. The distinct change found in the fatty acids - decrease of the free fatty acids level.

These changes seem not to be typical for wide-band noise influence.

A decrease of the glucose level was stated only within the first days of exposition in the animals although the hormon level changes in urine and tissue seem to be distinct during all time of expositions.

The results obtain with rats haven't been compared directly to man but it seems probably that ultrasonic noise caused neurovegetative changes.

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EFFECTS OF 8 h EXPOSURE TO INFRASOUND IN MAN

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INTRODUCTION

Infrasound is defined as air-borne sound within the frequency range below 20 Hz. The human ear is quite insensitive to low frequencies as is shown by the illustration of the auditory threshold in Fig.1 but it is capable of perceiving infrasound down to approx. 1.5 Hz (Yeowart, 1976).

Although measurements of the auditory thresholds in the infrasound range have been conducted more than 40 years ago (Békésy,1936) the wrong concept of a principal inaudibility of infrasound is still widespread.

The effects of short-term exposure of man to intensive infrasound have been studied thoroughly (for review see v.Gierke and Parker,1976). The purpose of this report is to describe effects of mild infrasound after 8 h of exposure.

MATERIALS AND METHODS

For the purpose of studying effects of prolonged infrasound exposure, a room of 2.9 x 2.0 m floor area and a ceiling height of 2.3 m was equipped with 24 low-tone loudspeakers fixed to one of the walls. The room had one window and was suitable for a permanent stay of persons.

The 24 low-tone loudspeakers (Isophon type 30/37) were driven by a 250 W power amplifier (BMT).

The exposure room was designed in such a way as to have the greatest possible homogeneity of the infrasound field within the entire room when the door was closed. On the other hand, a strong infrasound pressure gradient in the door was present when the door was open.
In this room, a total of 100 test persons was exposed to a number of different exposure conditions. The duration of exposure per person varied from several minutes to 8 h per day on 5 suc-

cessive days. The total period of infrasound exposure for all test persons amounted to ca. 2 000 h. The sound pressure level varied from 70 dB to 125 dB (with earphones, to 140 dB). The frequencies varied from 3 Hz to 24 Hz. In short-term exposure experiments, pure tones as well as band noise were applied as pressure field, pressure gradient field and in- and antiphase earphone exposure.

The 8 h exposure experiments were carried out in the pressure field.

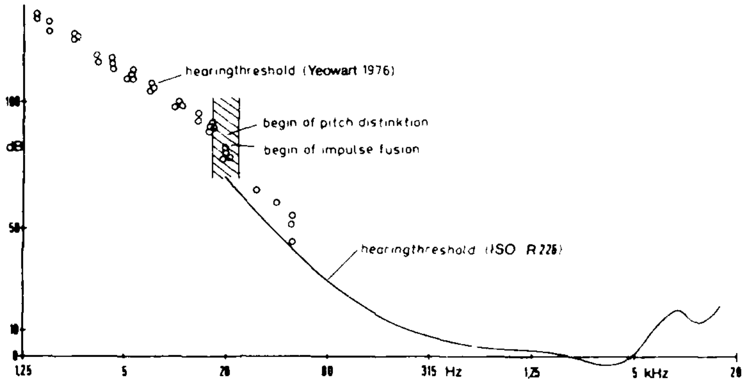

Fig. 1 Human hearing threshold

Experiment 1

28 test persons of both sexes were exposed to an infrasound pressure field - third octave band noise with a 12.5 Hz centre frequency and a continuous sound level of 110 dB for 8 h. Control sessions of identical length took place for half of the test persons one day before exposure, for the other, after exposure.

The test persons had to complete a questionnaire at the end of each session. The queries had to be answered in accordance with the following five-grade scale:

1) not true; 2) less true; 3) moderately true
4) rather true; 5) positively true.

Spontaneous statements by the test persons wer also recorded.

In parallel to this, a number of physiological parameters were established (Ising et al., 1982) which, however, have not been described in detail in the present paper.

Experiment 2

18 males aged 18 to 30 years (average 24 years) served as test persons. Each test person was scheduled to work on ten consecutive days separated by one week-end. The first day (control conditions) was to enable a habituation to the experimental situation; it was not included in evaluation. The experi-

mental conditions had been distributed over the remaining nine days as follows:

3 x	control	
1 x	infrasound 3-6 Hz	110 dB
1 x	infrasound 6 - 12 Hz	110 dB
1 x	infrasound 12 - 24 Hz	110 dB
2 x	traffic noise	75 dB (A)
1 x	traffic noise + 6-12 Hz infrasound	

To avoid effects due to the sequence of exposure conditions, a Latin square was set up.

In the exposure room, two test persons (A + B) each were placed 59
at one desk (for arrangement of measuring equipment see Fig.2).

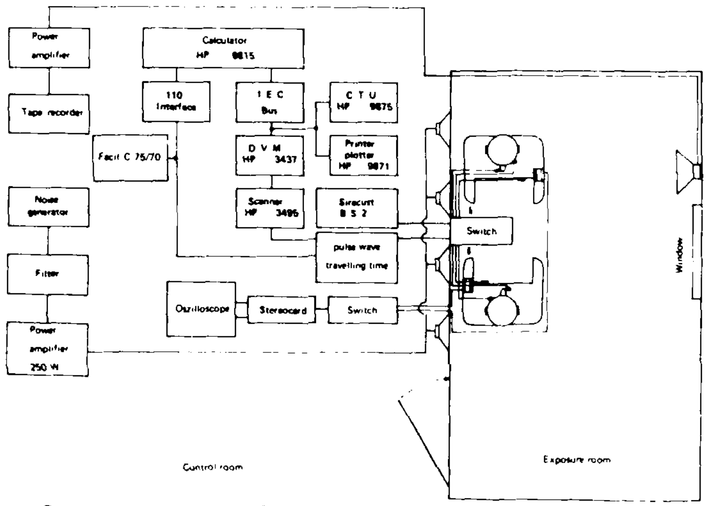

Fig. 2 Experimental set-up

They had been fitted with ECG electrodes, a temporal pulse sensor and a respiratory rate sensor (nose). The cuff of the blood pressure recording device had been fitted to the upper left arm. Measuring and sound-producing equipment had been installed in an adjoining room. Test persons A and B could be alternatively connected to a semi-automatic blood pressure recorder (Stereocard, Dr. Lange, Berlin). The filtered Korotkoff signals and the trigger impulses controlling the pressure gauges of the Stereocard device were visualized by a double beam storage oscilloscope, so that doubtful measurements could be eliminated.

The parameters, heart rate, respiratory frequency, temporal pulse, and pulse wave travelling time were measured by means of computer-controlled data recording equipment.

One measuring cycle for the two test persons took 20 min. Blood pressure was recorded during this period. During the entire period (8 h), urine was collected in a bottle containing

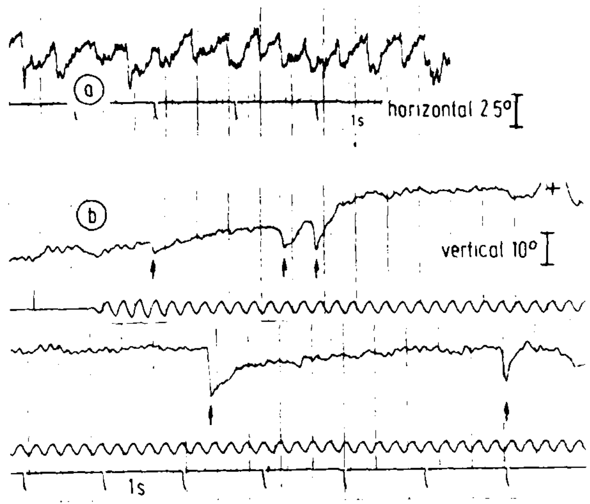

Fig. 3 Registration of direction of sight in a test person

a) Caloric nystagmus, horizontal plane caused by rinsing the right ear with water of 17°C

b) Non-periodic nystagmus-like jerks of the eye after the beginning of antiphase earphone exposure, 5 Hz, 135 dB (+ blinking)

hydrochloric acid. Upon termination of work, the urine volume was determined and a urine sample adjusted to pH 3 to 4 and stored under refrigerated conditions. Epinephrine and norepinephrine were determined by fluorimetry after one week at the latest (for method see Ising et al., 1980). Following these examinations, c-AMP was determined in deep-frozen urine samples.

Questionnaires had to be completed during the lunch break. It contained questions about the psychological tension, tiredness and loss of efficiency of the subjects.

RESULTS

Infrasound within the range of the maximal level observed in machine areas, public transport etc. has been found to cause neither disturbances of equilibrium nor real nystagmus or nausea. Only in one test person out of five, anti-phase earphone exposure (135 dB, 5 Hz) caused single nystagmus-like eye movements (Fig. 3, indicated by arrows). They appeared at stochastic intervals and were more frequent at the beginning of exposure than later on.

Experiment 1

The results of the questionnaire inquiry have been repro-

duced in Table 1, where δ_m represents the averaged scale value difference of the answers given by test persons following infrasound exposure and control situations, respectively. Infrasound exposure that meant a nuisance was represented by a positive δ_m In the last column of the table, the probability of error p calculated by the t test indicates whether the δ_m values were incidental or meant significant effects of infrasound. The influence of infrasound was greatest in respect of the concentration power. The second place was occupied, with equal shares, by nuisance and exhaustion due to infrasound.

Table 1 Results of questionnaire inquiry

δ_m : Mean difference of scale values for infrasound exposure and control conditions

p : Probability of error established by the t test

Statement		δ_m	p
It takes more effort than usual to keep something in mind		1.4	0.001
I feel I need some rest		0.8	0.001
I am content with working conditions		0.8	0.01
I feel	disturbed	0.75	0.05
I feel	a need of recovery	0.7	0.001
I feel	unaffected	0.7	0.01
I feel	annoyed	0.7	0.05
I feel	quiet	0.6	0.001
I feel	attentive	0.6	0.01
I feel	well	0.6	0.01
I feel	listless	0.5	0.05
I feel	exhausted	0.4	0.05
I feel	dumb	0.4	-
I feel	fully awake	0.3	-
I feel	sullen	0.2	-
I feel	giddy	0.1	-
I feel	sleepy	0.05	-

- - - - -

Judging by spontaneous statements, only 5 out of the 28 test persons felt completely uninfluenced. The remaining 23, when exposed to infrasound, made the complaints listed in Table 2.

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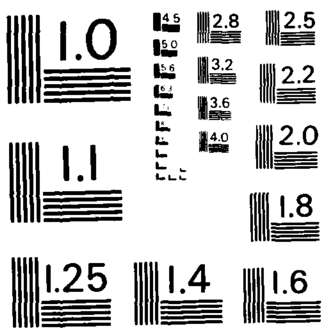
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Table 2

Spontaneous remarks on subjectively experienced influence of infrasound

Number of test persons	28
thereof completely uninfluenced	5
more or less intensively felt influenced	23
1) reduced concentration power	8
2) increased tiredness upon termination of test situation	7
3) increased feeling of tenseness during test situation	3
increased feeling of tenseness upon termination of test situation	6
4) sensation of pressure upon the ear	5
5) unpleasant sensation like "vibration"	3
6) slight indisposition when watching a movie during sound exposure	2
7) increased effort needed for learning	2
8) headache	1
9) feeling of giddiness	1
10) noise-associated nervousness	1
11) roaring sensation in head and ears	1
1 - 4 hours after termination of test situation:	
12) headache	2
13) indisposition	2
14) particular fatigue	2

\- - - - -

The physiological parameters recorded (blood pressure, heart rate, finger pulse amplitude) were not significantly altered by infrasound (Ising et al., 1982).

Experiment 2

The results of the questionnaire inquiry are given in Table 3.

Table 3

Psychological state of test persons

Differences between control and exposure conditions

Statement	3-6 Hz	110 dB 6-12 Hz	12-24 Hz	75 dB(A) TN
1) tense	.45^{xx}	.39^{xx}	.39^{xx}	.73^{xxx}
2) dissatisfied	.34	-.05	.23	.45^{x}
3) fit	-.13	-.25	-.41^{x}	-.75^{xx}
4) irritable	.14	.20	.25	.53^{x}
5) tired	.41	.03	-.36^{x}	.30
6) restless	.45^{xx}	.22	.34^{x}	.50^{x}
7) fresh	-.56^{x}	-.45^{x}	-.17	-.61^{xx}
8) excited	.08	.03	.03	.019
9) lively	-.43	-.20	-.03	-.42^{x}
10) ill-tempered	.14	-.02	.03	.25
11) awake	-.48^{x}	.02	-.03	-.25
12) able to concentrate	.08	-.03	-.20	-.42

Significance levels (Wilcoxon test) -

x = 0.05

xx = 0.01

xxx = 0.001

The statements were grouped by the following dimensions:

1) Placidity versus tension: "tense", "irritable", "restless";

2) Vigour versus tiredness: "tired", "fresh","lively","awake";

3) Fitness versus loss of efficiency: "able to concentrate", "fit";

4) Good versus bad mood: "ill-tempered", "irritable"

In the dimension "tiredness", there was a remarkable decrease with increasing frequency, the difference between the conditions 3-6 Hz and 12-24 Hz being significant ($p < 0.01$). The frequency dependency of the first three dimensions is shown in Fig. 4. Examples of the automatically recorded parameters are given in Fig. 5.

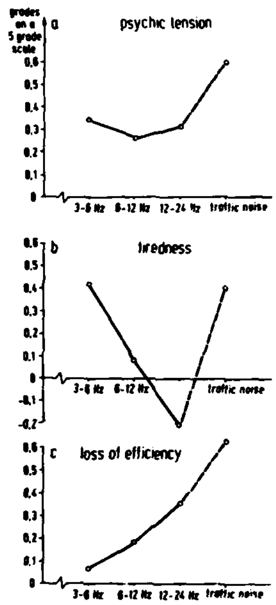

Fig. 4 Psychological reactions to infrasound and traffic noise

The results of the physiological and biochemical measurements are listed in Table 4. Additionally, the significant alterations as compared to the control conditions are listed in Table 5.

There were some slight increases of catecholamines and blood pressure and a corresponding decrease of pulse wave travelling time, indicating a slight stress effect of infrasound. It may be of interest to mention the significant depression of the respiratory rate observed at the lowest infrasound frequency.

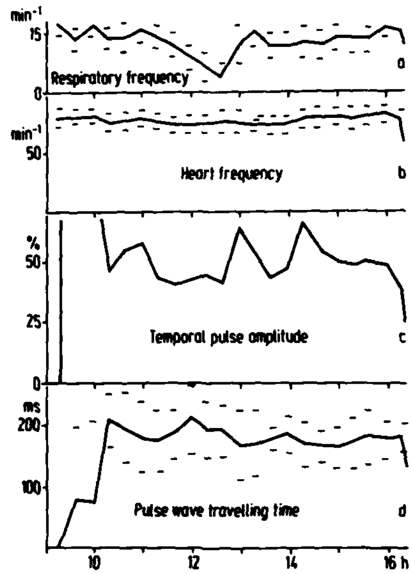

Fig. 5 Example of automatically recorded physiological parameters of one test person (mean values over 9 min each and s.d.)

Table 4

Mean values of physiological and biochemical parameters established under control and exposure conditions

	Control	110 dB 3-6 Hz	110 dB 6-12 Hz	110 dB 12-24 Hz	75 dB(A) Traffic noise
Blood pressure systolic (mm Hg)	115.4	115.6	116.1	117.3	116.2
Blood pressure diastolic (mm Hg)	76.6	76.2	76.8	77.6+)	77.4+)
Heart rate (min^{-1})	71.6	73.7	70.9	72.3	74.2
Respiration rate (min^{-1})	16.3	15.6++)	15.9	16.1	16.4
Pulse wave travelling time (ms)	192.4	193.3	189.9	188.5	183.6+)
Epinephrine (µg/8 h)	4.27	4.98	4.89+)	5.13+)	4.59
Norepinephrine (µg/8 h)	11.1	12.3	12.4	12.3	13.4+)
c-AMP (µmol/8 h)	2.02	2.08	2.03	2.12	2.13

Significance levels (Wilcoxon test) -

+) $p < 0.05$

++) $p < 0.01$

Table 5

Comparison of exposure and control conditions
Significant alterations of parameters:

Parameter	110 dB 3-6 Hz	110 dB 6-12 Hz	110 dB 12-24 Hz	75 dB (A) Traffic noise
Psychic tension	xxx		xx	xxx
Fitness		x	xxx	xxx
Mood	x		xx	xxx
Epinephrine		x	x	
Norepinephrine				x
Respiratory rate	xx			
Blood pressure diastolic			x	x
Pulse wave travelling time				x

Significance levels (Wilcoxon test) -

x = 0.05
xx = 0.01
xxx = 0.001

Discussion

The results show that infrasound acts as a non-specific stressor in a similar way as does audiosound. The stress effects of infrasound will rise with the subjectively perceived loudness, i.e. both with rising sound pressure and rising frequency.

According to Yeowart (1976), the mean loudness levels of the 110 dB infrasound octave bands are

frequency/Hz	loudness level/phone
3 - 6	10
6 - 12	50
12 - 24	90

While the stress effects of infrasound increased with the perceived loudness, a special infrasound effect has shown an opposite tendency. Infrasound near the hearing threshold caused a significant depression of the respiratory rate and an increase of tiredness and psychological tension. The following considerations may explain these effects. In nature, sound has the function of a warning signal. Distant thunder and other noises have a low frequency spectrum because of the frequency-dependent dissipation of soundwaves. Humans automatically concentrate to detect such low frequency noises near the hearing threshold and stop breathing for a short time. Normally, this concentrated listening will last only for a few moments and is repeated from time to time if the noise continues. This may explain the decreased respiratory rate and increased tension and tiredness.

Sensitized persons, however, are not able to stop concentrating on such low frequency noises near the hearing threshold. A forced concentration on long-lasting nearly inaudible noises may therefore be the cause of the strong, annoying action of low-frequency soft noise on sensitive persons (Leventhall, 1980).

In contrast to suggestions by Gavreau (1968), we did not find infrasound effects like disturbances of equilibrium, nausea or real nystagmus. The sporadically recorded jerks of the eyes in one test person may explain the reports by Evans and Tempest (1972). However, these eye movements were not periodical and vanished shortly after the beginning of exposure.

Conclusions

In this study, effects of inaudible infrasound were not detected. Infrasound near the hearing threshold may force sen-

sitive persons to listen with high concentration and thus may affect these persons strongly. In normal persons, infrasound acts as a non-specific stressor. The stress effects increased with increasing subjectively perceived loudness.

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PHYSIOLOGICAL EFFECTS OF ENVIRONMENTAL NOISE ON NORMAL AND MORE SOUND-SENSITIVE HUMAN BEINGS

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INTRODUCTION

For a periode of more than seven years the TNO Research Institute for Environmental Hygiene has carried out an investigation into the influence of noise exposures of longer duration on blood circulation and respiration. In a first investigation carried out in the Institute it was found that two-hour exposure to fluctuating white noise and traffic noise caused larger effects in the physiological parameters measured than two-hour exposure to constant white noise with even higher equivalent sound levels. Therefore, a second investigation was carried out into the physiological effects of different environmental noises with a fluctuating or impulsive character.

Physiological effects on normal and more sound-sensitive human beings have been determined in this second investigation. In this paper some details about this investigation are presented.

EXPERIMENTAL METHOD

Experiments with "normal" subjects

In total 88 experiments were carried out with fifteen subjects. These

subjects were healthy and had no special problems with regard to noise. In this paper they are called "normal" human beings.

Of the fifteen subjects eight (4 women, 4 men) were aged between 20 and 30 years and the other seven (3 women, 4 men) between 40 and 66 years.

During six different experiments the subjects were exposed both to road traffic, aircraft, railway and synthetic impulsive noise and quiet. The aim was to study the effects caused by a two-hour exposure on the heart rate, the vasoconstriction, the systolic and diastolic blood pressure and the respiration rate.

During an experiment a test subject was alone in an air-conditioned room. During the whole experiment the subject sits on a bench. The background noise level in the room was about 35 dB(A). When there was no task to be carried out the subjects were permitted to read a magazine or a book during the experiment. Most experiments were carried out in the morning and there was only one experiment a day.

Each experiment can be divided into three periods:

- Period 1, quiet, duration 1 hour. In the last 20 minutes, the physiological signals are recorded.
- Period 2, duration two hours. The test subject is exposed to noise and carries out a task.
- Period 3, recovery period, duration one hour. Without exposure to noise, just as period 1.

During the last two periods also the physiological signals are recorded.

To see whether any effects caused by noise occurred, the subjects also participated in control experiments without exposure to noise in period 2.

During period 2 of the experiments with noise exposure and one control experiment the subject's task was to look for a small red coloured dot in some of the slides projected on a screen. The aim of this simple task

was to keep the test subject alert. In all experiments the equivalent sound level during the exposure to one of the noises was 75 dB(A). The road traffic noise was recorded in a town near a crossing of a very busy highway with traffic lights. The railway noise was recorded near a station where a lot of through trains pass. The aircraft noise was recorded in a forest near a big airfield. The impulsive noise consisted of synthetic impulses.

Experiments with "sound-sensitive" subjects

After the above-mentioned experiments more experiments were carried out with nine subjects who were more sensitive to sound. By means of articles in newspapers the Institute reported results of just described experiments and asked people considering themselves sensitive to noise to contact. About hundred people reacted. By means of a questionnaire, a personal talk and a visit to their homes nine persons were selected. They all felt themselves threatened by noises, were influenced physically or mentally in a serious way, or were annoyed, agressive or rebellious. After a further study of their living environment these nine "sound sensitive" persons were exposed to noise during several laboratory experiments. All were exposed to traffic noise. Depending on their personal sensitiveness some of them were exposed either to aircraft noise or to impulsive noise or to pure tones combined with constant white noise.
The experimental set-up was the same as described in the first part of this paragraph. All sensitive subjects participated in a control experiment without noise exposure. During period 2 of the experiments (including the control experiments) they carried out the task.
Period 2 lasted only one hour.

Physiological measurements

The physiological signals taken from the normal and the more sensitive subjects were converted into electrical signals and then processed by computer. During the whole experiment the number of heart beats and respirations were counted each minute. Volume changes of the arterial blood circulation were measured with an impedance plethysmograph. In experiments with normal subjects the electrodes were placed around the arm and in the experiments with the sound-sensitives around the finger.

From the relative part of the impedance plethysmogram, the 'mum value of the signal, occurring as a result of a contraction of t ıeart, was determined, and for each minute the mean value was calculat ˏy computer. A reduction of the amplitude of the relative impendace plethysmogram is a result of a vasoconstriction.

Every five minutes the systolic and diastolic blood pressure was measured automatically. For all periods and all parametersthe median value was calculated. From all values of the parameters of the periods 2 and 3 so-called normalized values were derived by relating them to the corresponding values during period 1. In this way it was possible to compare results of different experiments and exposures with each other.

RESULTS

Physiological effects on normal subjects

For all subjects together the means of the normalized values were calculated for the period 2 and 3 for each physiological parameter and for each different type of experiment. In comparing the values of the control experiments and those of the experiments with noise exposure various sta-

tistically significant changes due to noise exposure were determined in period 2. The percentiles of these changes are given in table 1. In all cases the increase in the heart rate or respiration rate, during exposure to one of the noises was statistically significant.

Impulse noise caused the largest effects in respiration rate and almost the largest in heart rate. Also an increase in the systolic and diastolic blood pressure was found. Again impulse noise caused the largest and also statistically significant increases in blood pressure. Compared with control experiments with a task noise causes a small vasodilatation, indicated by an increase of about 1.5 % in the amplitude of the plethysmogram. Comparing the values of period 3 (recovery period) of the control experiments and those of the noise experiments it was observed that within one hour after ending noise exposure most physiological parameters were going back to their baseline level. Table 1 shows the percentiles of the relative changes of these values.

Table 2: Subjective experience

Noise source	% of subjects that were very annoyed or annoyed
Impulse noise	76.9 %
Railway noise	61.5 %
Road traffic noise	50.0 %
Aircraft noise	57.1 %

Road traffic noise and sound-sensitive subjects

In their living environment most of the nine sound-sensitives were very much annoyed by road traffic noise. Therefore, all nine subjects were exposed to road traffic noise (L_{eq} = 75 dB(A)) in our laboratory. For all these subjects the same calculations as for the "normal" subjects were

made. Table 3 shows the relative changes due to road traffic noise both for the sound-sensitive and the normal subjects. The "sound-sensitives" show an increase in the heart rate and respiration rate of more than 3 %. Although the exposure period for the sound-sensitives was shorter (1 hour) the relative changes are larger. Further the sound-sensitives show a vasoconstrictive reaction in the finger and the ear lobe.

Table 1 - Relative changes in physiological parametersof normal subjects due to noise exposure

Relative changes in physiological parameters in %.										
Noise during period 2	Vasocon-striction		Heart rate		Respira-tion rate		Blood pressure			
							Systolic		Diastolic	
	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
Trains	-1.0 n	-2.8 n	+4.5 s	+3.7 s	+3.4 s	-6.5 s	+2.8 s	+2.7 s	+0.2 n	-0.4 n
Road traffic	-2.9 s	-1.1 n	+2.4 s	-0.5 s	+1.4 s	-1.6 s	+3.1 s	+2.7 s	+1.5 n	+2.1 n
Air-crafts	-2.7 n	-3.1 n	+2.3 s	0.2 n	-1.6 s	-6.4 s	+4.8 s	+2.9 s	-0.2 n	-2.6 n
Impulses	+0.6 n	+2.8 s	+4.3 s	3.1 s	+4.9 s	0.3 n	+5.0 s	+3.7 s	+3.7 s	+0.5 n
Mean	-1.5	-1.1	+3.4	+1.6	+2.0	-3.6	+3.9	+3.0	+1.3	-0.1

s: statistically significant difference (p = 5 %)

n: not statistically significant (p = 5 %)

(2): noise exposure period compared with same period of control experiment with a task

(3): period 3 (recovery) compared with same period of control experiment with a task

Subjective experience of normal subjects

Impulse noise seemed to be the most annoying of all noises. In table 2 the annoyance percentiles are given for all noise exposures.

Table 3 Physiological changes due to road traffic noise

Physiological parameter	Relative changes in % (2)	
	Sound-sensitives	Normals
Vasoconstriction in arm	(1)	-2.9 s
Vasoconstriction in finger	+3.0 n	(1)
Vasoconstriction in ear	+6.2 s	(1)
Heart rate	+3.3 s	+2.4 s
Respiration rate	+3.1 n	+1.4 s
Systolic blood pressure	+3.3 n	+3.1 s
Diastolic blood pressure	+3.0 n	+1.5 n

(1): not measured

(2): noise exposure period compared with same period of control experiment with a task

s : significant difference (p = 5 %)

n : not significant

Individual reactions of sound-sensitive subjects

During exposure to road traffic seven of the nine subjects showed an increase in parameters of blood circulation and respiration. Although the equivalent sound level during the experiment was much higher than in their own living environment they felt the same stress.
Some of the sensitive subjects were also exposed to noise from aircrafts or impulsive noise. After the experiments they were asked about their subjective experience. Most complaints about the noise exposure were also found as physiological changes in the relevant parameters. During a special experiment one of the subjects was exposed to the same noise as was found in her living environment. At a distance of 500 m from her house there was a factory which produced a sound like white noise of

about 50 dB(A) and also a tonal sound (400 Hz) with peaks up to 57 dB(A). No other sound components above 25 dB(A) were measured. In our laboratory the same situation was composed. The test schedule is given in table 4.

Table 4 Test schedule for a special experiment on one subject

Period in minutes	Exposure
1: 0- 25	Silence 30 dB(A)
2: 25- 45	Silence and task
3: 45- 65	White noise 45 dB(A) and task
4: 65- 85	White noise 45 dB(A), 400 Hz tone of 45 dB(A) and task
5: 85- 115	White noise 45 dB(A)
6: 115- 125	White noise 45 dB(A), 400 Hz tone increasing from 45 dB(A) to 55 dB(A)
7: 125- 175	Recovery

Figure 1 shows the changes in respiration rate, heart rate and the plethysmogram of the finger during the various periods mentioned in table 4.

The first time (period 4) the subject was exposed to the 400 Hz tone no effect in physiological parameters was shown. Probably the tone was masked by white noise. Then in period 6 the subject was exposed again to the 400 Hz tone. The sound level increased slowly from 45 dB(A) to 55 dB(A). At the moment the 55 dB(A) sound level was reached the subject reacted very emotionally and panicked. The heart rate increased from 75 beats per minute to 120 - 130 beats per minute. In the finger a vasoconstrictive reaction of almost 70 % from the baseline (100 %) was determined. The irregularity between heart beats also doubled in that period. The systolic blood pressure increased with 15 mm Hg whereas the diastolic

blood pressure increased with only 4 mm Hg.

Undoubtedly this person showed physiological effects especially in parameters of blood circulation which were very much higher than determined in other experiments. The direction of these changes was the same.

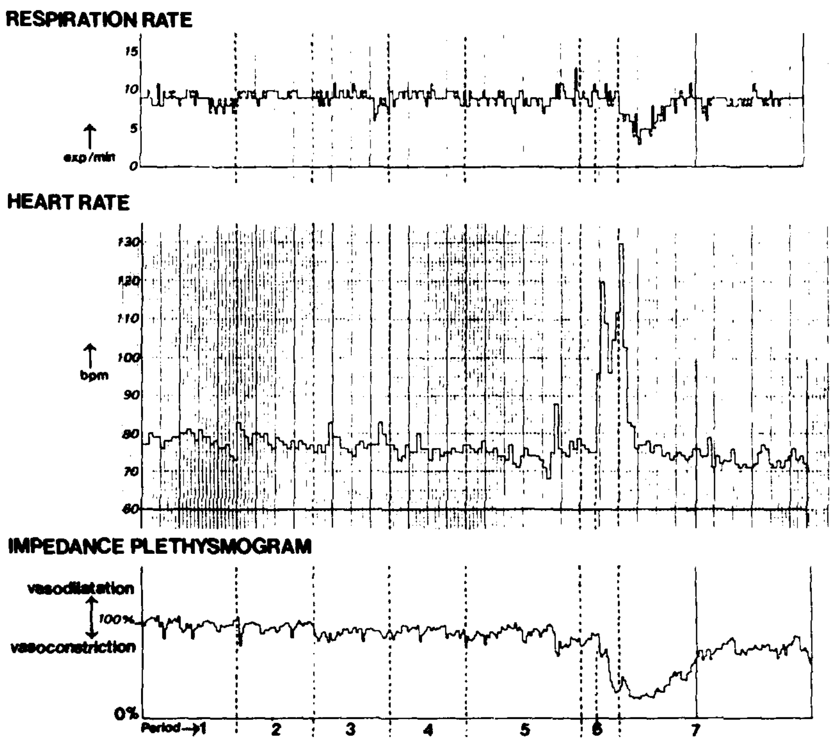

Fig. 1 - Physiological effects on one particular subject caused by white noise and a tonal sound of 400 Hz.

CONCLUSIONS

It can be concluded that exposure to environmental noise with an equivalent sound level of 75 dB(A) causes a statistically significant increase in the heart rate and respiration rate, a small increase in the systolic blood pressure and some vasoconstrictive changes. Changes of 3 up to 5 % were determined in heart rate and respiration rate. Sound-sensitive

subjects reacted with larger changes than normal subjects . Only sound-sensitive subjects when exposed to road traffic noise reacted with a vasoconstriction of about 3 % and 6 %, respectively, in finger and ear lobe. In some cases sound sensitive subjects were exposed in our laboratory to noise which annoyed them very much in their daily lives.
Mostly they reacted with large changes. Especially in one case exposure to her own daily sound caused tremendous effects as doubling the heart rate, a 10 to 15 mm Hg increase of the systolic blood pressure and a vasoconstrictive reaction up to 70 % below the baseline (100 %).

The tendency to the increase in parameters of blood circulation and respiration, when subjects are exposed to noise can be explained if noise is considered a stressor.

These results lead to considering two kinds of future research in laboratory:

- study of the effects of long-duration (8 hours) environmental noise exposure with equivalent sound levels lower than 75 dB(A) on the heart rate and respiration rate to establish the level which causes no effects;
- psychological and physiological experiments in which sound exposure is combined with the personal sound sensitiveness of the subjects.

Perhaps it is possible to combine these two aspects.

INDUSTRIAL NOISE, ANNOYANCE AND BLOOD PRESSURE

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INTRODUCTION

Results of an experimental study and an epidemiological study in industry on extra-auditive effects of noise, will be presented, as far as they reflect annoyance and blood pressure.

Much experimental research on noise and blood pressure has been carried out. In most experiments diastolic blood pressure increased, whereas systolic blood pressure did not show a consistent reaction-pattern (Andrén et al 1978, 1980; Geltischeva 1972; Ising et al 1980 (a) (b). Almost all experiments, however, were performed on resting subjects under laboratory conditions. Extrapolation to industrial conditions, therefore, can at most be approximative. To carry out this study we tried to find an industrial setting. However, a pilot-study in industry taught us that noise exposure, dynamic and static muscle exercise and mental stressors were too difficult to control. We had to return to the laboratory to plan a well-controlled experiment, simulating industrial conditions. The difference between this study and most other experiments is that blood pressure was measured on subjects doing light physical work.

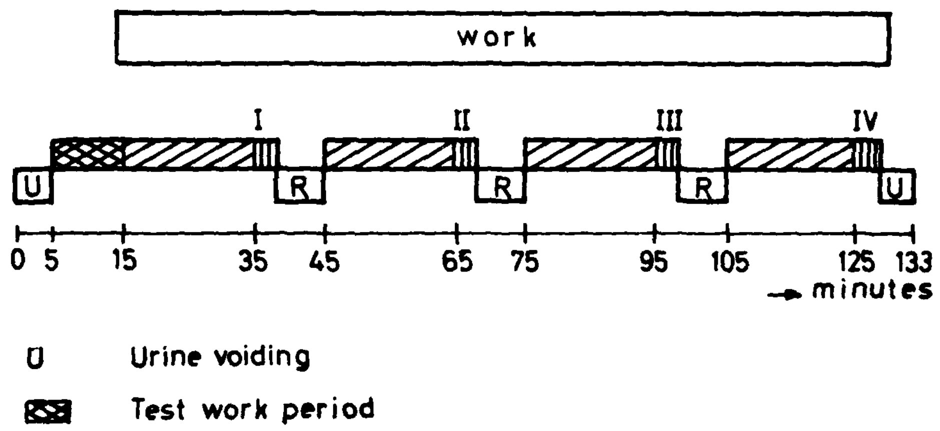
In some epidemiological studies higher blood pressures are measured in noise-exposed workers in industry; in other studies such differences are not observed (Doyon et al 1978; Jansen and Gros 1978; Kaliciński et al 1975; Malchaire et al 1979; Manninen and Aro 1978; Verbeek et al 1980). In most studies it was not possible to consider the other working conditions seriously. In some cases the blood pressure meter might give biased readings. No corrections for the effects of age and relative weight on blood pressure were made in every study. To overcome some of these difficulties we performed some epidemiological studies, one of which is presented here.

Surprisingly studies of annoyance by noise in industry are very rare in contrast to studies of annoyance by noise in the outside environment. In our study we paid special attention to this subject. Annoyance might be an intermediate to noise effects like blood pressure and in itself might have a negative effect on the quality of work.

LABORATORY EXPERIMENT

MATERIAL AND METHODS

Twentyfour male subjects (21-33 yr) performed four periods of light physical work under laboratory conditions. Each period lasted 133 minutes containing 10 minutes for work without noise followed by a blood pressure measurement to get used to the procedure, and four times 20 minutes for work under noise or non-noise conditions (scheme).



Work

Blood pressure measurement I to IV

R Rest in quiet room

Dynamic muscle exercise was hardly done. Subjects were standing and did some static muscle exercise with the arms. Time pressure and other mental stressors were absent. The mean noise level (Leq), measured by personal noise dosemeters (CEL 179 B), was 98 dBA (range 94.5-99.0 dBA) with maximum noise levels at 2, 4 and 8 kHz. All subjects worked two periods with perforated earmuffs and two periods with intact earmuffs, in order to compare blood pressure with and without noise exposure. The lowest 25% percentile of the attenuation of the intact earmuffs was 34-43 dB for 1, 2, 3, 4 and 6 kHz.

The test-sequence for each subject was randomized in order to avoid influence on the total results. Blood pressure and heart frequency were measured four times at the end of every 20 minutes work. Each measurement was done three times, the second and third measurement were used for analysis. Measurements were done by an automatic blood pressure meter (Dinamap 845^{R}) working on oscillometric principle; during the measurements the subjects stood in working position, wearing their perforated or intact earmuffs in the noisy work environment.

At the start and at the end the subjects were asked to avoid as much urine as possible; the latter portion was collected and analyzed by a HPLC-method for catecholamines.

RESULTS

The mean diastolic blood pressure of all subjects was significantly increased during noise conditions, if compared with the control conditions. The difference was small: 1 mm Hg. The mean systolic blood pressure and heart frequency did not differ significantly (table 1)

Table 1. Blood pressure (mm Hg) and heart frequency (beats/min) under noise and non-noise conditions

	noise	(s.d.)	control	(s.d.)	difference of means	
mean systolic b.p.	127.8	(7.85)	127.4	(8.26)	0.4	n.s.
mean diastolic b.p.	75.2	(6.24)	74.1	(5.95)	1.1	p < 0.5*
mean heart frequency	77.5	(11.93)	78.9	(11.56)	-1.4	n.s.

* p<.05, paired T-test, one-tailed.

The mean course of blood pressure and heart frequency during the experiments is shown in Figure 1. Each value represents the mean value of 96 measurements. Diastolic blood pressure was significantly higher during noise conditions at time I, heart frequency was significantly lower at time III (paired T-test, $p < .05$, one-tailed). The mean excretion of adrenaline and noradrenaline in the urine did not differ between both conditions (table 2).

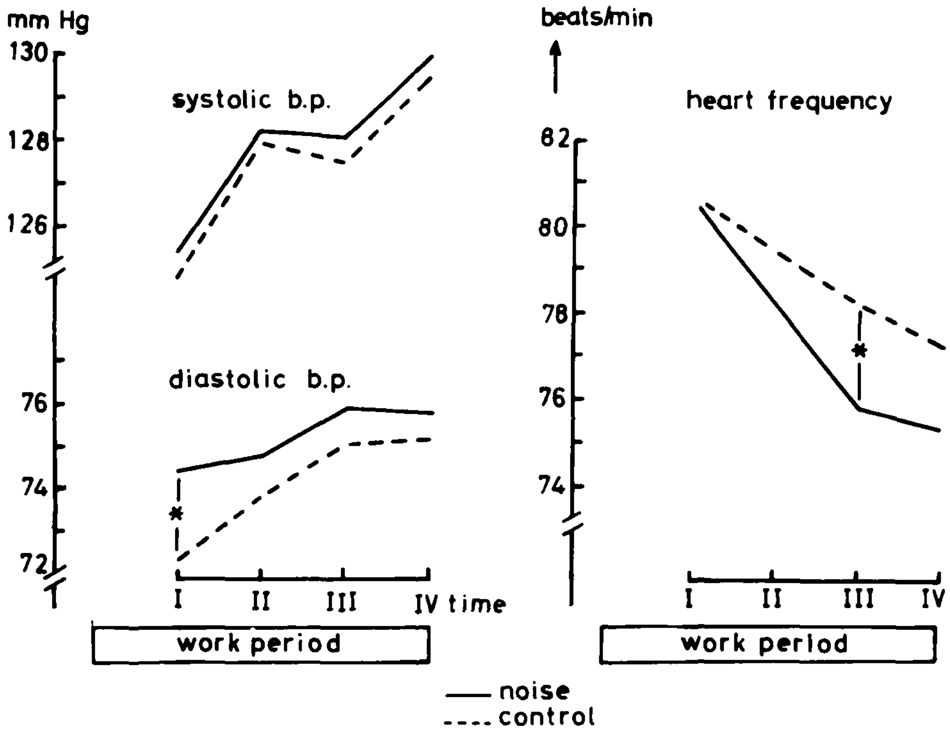


Fig.1 - Blood pressure and heart frequency under noise and non-noise conditions.

Table 2. Mean (nor)adrenaline excretion (ng/mmol creatinine) during noise and non-noise conditions

	noise	(s.d.)	control	(s.d.)	difference
noradrenaline	1672	(530.1)	1654	(598.2)	18 n.s.
adrenaline	492	(229.5)	459	(242.3)	33 n.s.

paired T-test, two-tailed

DISCUSSION AND CONCLUSION

Diastolic blood pressure was slightly increased under noise-conditions. This is in good agreement with results of other experiments. The effect of noise, however, was small. One possible explanation of the small effect in this experiment is the influence of static work on blood pressure, overshadowing an effect of noise.

In other experiments elevation of adrenaline excretion has been observed particularly when also other stressors than noise (e.g. mental stressors) were present (Andrén et al 1978; Ising et al 1980(a); Klotzbücher und Fichtel 1978, 1979). In other words: noise might have been not disturbing enough in our experiment.

EPIDEMIOLOGICAL STUDY

MATERIAL AND METHODS

In an epidemiological study 539 male workers of seven factories were examined in cooperation with five occupational health services. At first a questionnaire was completed, subsequently a hearing test was carried out and blood pressure, lenth and weight measured.

For the hearing test various continuous audiometers, all calibrated, were used. Blood pressure was measured with a Waterpik Professional^R automatic blood pressure meter with a microphone in the cuff. Three measurements were made, the second and third were used. In one factory (n=116) blood pressure measurements were not carried out according to our instructions; these results were excluded.

In each factory noise exposure was measured with personal noise dosemeters in representative samples of workers at different locations and with different jobs. Most measurements were done by calibrated CEL 179 and CEL 172 noise dosemeters with a very fast time constant, some with calibrated Genrad 1954/9730 noise dosemeters (time constant slow). All dosemeters were worn in the breast pocket with the microphone attached to the collar. At all factories data on other recent noise measurements were available.

RESULTS

The non-respons was 27%; the most frequent reasons were sickness absenteism, language problems and holiday. From the age of 50 year onwards the relative number of workers in the study was rapidly declining as is usual

in Dutch factories.

In cooperation with local experts every worker was classified according to a noise level on basis of the results of 126 personal noise dosemeter measurements and of other recent noise measurements: 13% worked at 80-85 dBA, 28% at 86-90 dBA, 33% at 91-95 dBA and 25% at more than 95 dBA.

Burns and Robinson (1970) discovered that hearing loss was caused by noise according to an equal energy principle. The following formula for noise energy was the most useful to predict hearing loss due to noise (simplified and useful only between certain limits): noise energy = mean noise level (Leq, dBA) + 3,7 + 10 log exposure during (year). This formula was used to calculate noise energy levels to relate to extra-auditive effects of noise in longterm exposure. The noise energy classification is based upon mean noise level and years worked at the present department. Workers with noise exposure at other factories or departments were excluded (n=265). This noise measure was called Equal Energy (EE).

A second measure was constructed to give more emphasis to duration of exposure. Noise levels were coded 2 to 5* and exposure duration was measured as in EE. The simple product of noise level and duration of exposure was used as second noise measure to relate to longterm exposure: Level x Years (LxY).

Hearing protection was worn always or most of the time by 33% of the workers. The percentage increased with noise level (dBA) (r=.38, p .05). Workers with more annoyance by noise wore more protection than their col-

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* 80-85 dBA = 2
86-90 dBA = 3
91-95 dBA = 4
95 dBA = 5

leagues with less annoyance, corrected for noise level (dBA) ($r=.22$, $p < .05$). Older workers used less protection compared with younger ones. It is likely that hearing protection provided some protection against auditive and extra-auditive effects of noise.

By means of regression coefficients blood pressure corrections were made for the influence of age and relative weight (Quételet-index). No significant correlations were found between EE or LxY and the corrected blood pressure ($p > .05$). In figure 2 the percentage of workers with a high corrected blood pressure is presented at different EE-levels.

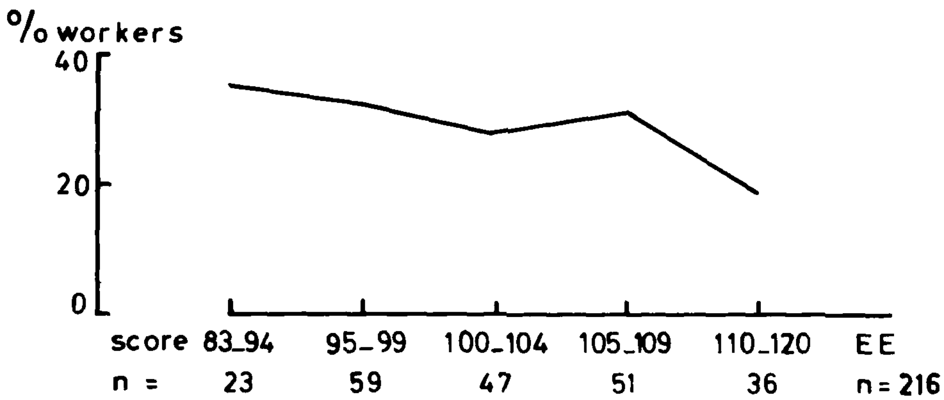

Fig.2 - Percentage of workers with a corrected systolic blood pressure ≥140 mm Hg and/or a corrected diastolic blood pressure ≥90 mm Hg at different EE-levels.

With respect to EE, an analysis was carried out in order to correct for confounding factors in the work environment. Only shiftwork emerged as a possible confounder. Shiftwork was positively correlated with EE, but shiftworkers had a lower corrected blood pressure than day workers, maybe

an *effect* of selection. However, neither shiftworkers (n=102) nor daywork-ers (n=108) showed a significant correlation between EE and blood pressure ($p > .05$) so the former association did not change. Use of hearing protection was not correlated to blood pressure; it could therefore not be a confounder.

The original blood pressure values did not increase above the age of 40-44 years. Workers becoming older maybe underwent a selection process connected with their health. To correct for this "healthy worker effect", another analysis was carried out only for workers younger than 45 years. No significant correlation, however, could be found between EE or LxY and the corrected blood pressure.

In the analysis with respect to hearing loss due tot noise, all workers were excluded with abnormal findings at the otological examination. Corrections for presbyacusis were made according to Spoor (1972). The greatest hearing loss at 3, 4 or 6 kHz at one or both ears after presbyacusis correction, was taken as measure of hearing loss due to noise. Hearing loss due to noise was positively correlated with EE and LxY (r=.26 and r=.30. $p < .05$, n=226) (figure 3). Two third of the workers was annoyed by noise. Many workers reported sometimes annoyance problems at work, probably because many noise sources had an intermittent caracter (fig.4). At least one particularly disturbing noise source was mentioned by 84% of the workers; 28% reported work tasks which were sensitive to being disturbed by noise. Tasks involving only mental load like administration, thinking, measuring and controlling, were mentioned 83 times, manual tasks 62 times (usually noisy tasks) and tasks involving conversation 33 times.

The correlation between the noise level and annoyance by noise as asked by a simple question on annoyance, was small, though significant (r=.11, $p < .05$). A higher correlation was found between noise level and conversa-

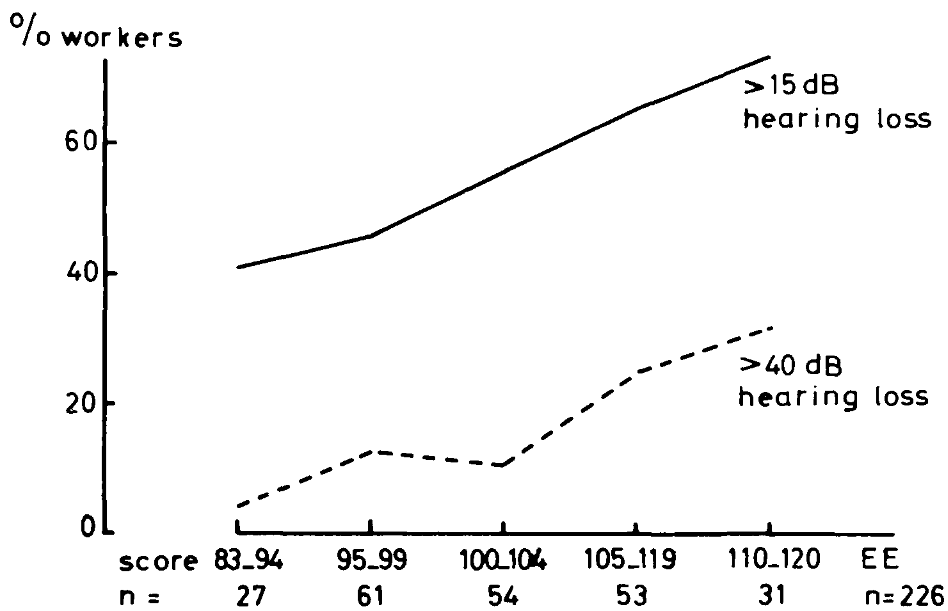

Fig.3 - The association between noise exposure (EE) and hearing loss due to noise as the percentage of workers have more hearing loss than 15 dB respectively 40 dB at 3, 4 or 6 kHz at one of both ears, after presbyacusis correction.

tional problems caused by noise ($r=.23$, $p < .05$) (fig.5). Annoyance by noise was not significantly correlated with age or number of years worked at the present department after exclusion of workers with noise exposure elsewhere ($p > .05$). No significant correlation could be found with hearing loss, independent of its cause. At noise levels 80-85 and >95 dBA, however, a significant positive correlation was found between hearing loss and conversational problems due to noise ($p < .05$).

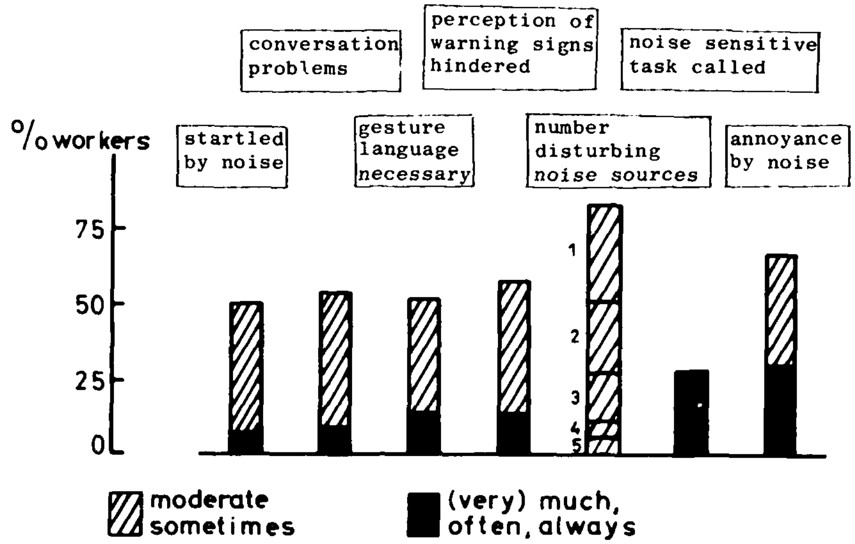

Fig.4 - Percentage of workers with complaints of different aspects of annoyance to noise (n=539).

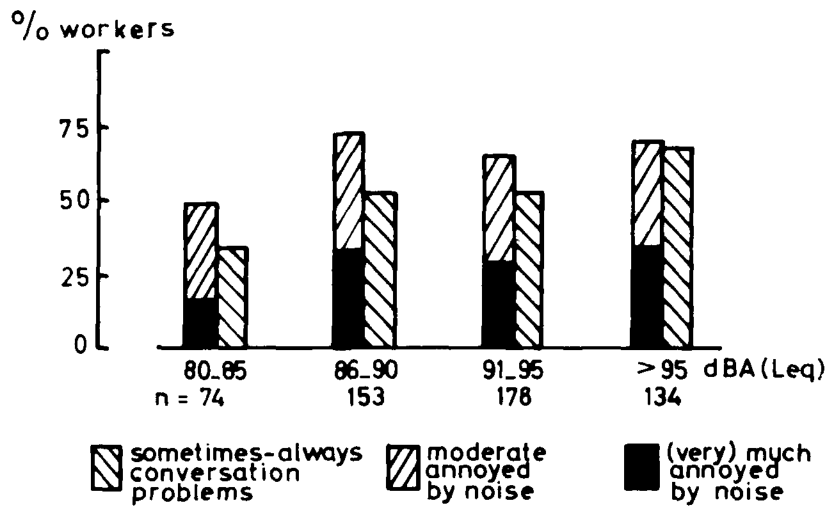

Fig.5 - Annoyance by noise and conversational problems in relation to the noise level.

DISCUSSION AND CONCLUSION

The positive relation between hearing loss due to noise and noise (EE) was once again confirmed. No significant correlation, however, could be found between exposure to noise and blood pressure, corrected for age and relative weight. Corrections for possibly confounding factors and for selection of older workers because of health did not change this finding.

The literature on this issue is inconsistent. Some epidemiological studies demonstrate a positive relation between noise exposure and blood pressure, other studies did not find that association. In this study, we could only correct for a part of the healthy worker effect. This might be a reason for not finding a positive relation between blood pressure and noise in this cross-sectional study.

Another explanation could be that so many factors like physical and mental strain, diet and genetical disposition influence blood pressure that it is nearly impossible to find differences in blood pressure due to noise, particularly when the effect of noise is relatively small.

Many workers were annoyed by noise. Questions on sources of disturbing noise resulted in much information that could be used to improve working conditions. Mental tasks were more sensitive to disturbance by noise than manual tasks. Annoyance by noise was lowest at 80-85 dBA but did not increase above this level in this study. Conversational problems, however, kept raising over increasing noise levels. Annoyance was not influenced by age or hearing loss. Habituation after years of working in a noisy environment could not be demonstrated.

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BODY SWAY CHANGES AFTER SINGLE AND PAIRED EXPOSURE TO NOISE AND WHOLE BODY VIBRATION

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INTRODUCTION

In man the center of gravity is high but the supporting surface formed by the soles of the feet is small. To maintain balance, good posture observation and a regulating system is therefore necessary. For example, many tasks carried out in work environments presuppose good regulation of the posture.

By studying the changes in the centers of pressure on the supportive surface of the soles, information can be gathered about the body's center of gravity, changes in the acceleration of the center of gravity and the functioning of the otoliths in the semicircular canals. Changes in the balance system can thus be estimated directly by studying body sway at a very low frequency (Nashner, 1971).

The purpose of the present study was to clarify whether intensive noise or low-frequency vibrations are significant in causing upringht body posture sway. Some earlier studies have apparently indicated that in the stabilogram frequencies

of 1 and 2 Hz are important borderlines in cases where the subjects were exposed to vibration alone. On the other hand, some studies have shown that intensive noise may cause dizziness and instability of the upright posture (Manninen, 1980). The same symptoms may occur at a very low noise, if the noise is directed at only one side of the body (Ades et al, 1957; Bell, 1966; Kryter, 1970).

MATERIAL AND METHODS

The present study is part of a long research program dealing with the individual and combined effects of noise, vibration, temperature and work on the hearing threshold, upright body sway and certain physiological functions. The study was carried out in a special exposure chamber. The principles underlying the exposure system and the details of the production and regulation of the exposure stimuli are described elsewhere (Manninen, 1982, 1983).

Ten healthy male student volunteers aged from 21 to 24 ($\bar{X} \pm$ s.d. = 22.7 ± 1.0 years) participated in the present study. There were six exposure combinations of noise and vibration, and a total of 60 experiments. The duration of each experiment was 1 hour 45 minutes, consisting of a control period of 30 minutes, three consecutive exposure periods of 16 minutes each, a four-minute measuring period and a recovery period of 15 minutes.

During the experiment the subjects were sitting in a vibration chair. Sinusoidal vibration at a frequency of 5 Hz and a peak to peak stroke length of either 6.0 mm or 7.0 mm was used. The vibration accelerations (rms) were correspondingly 2.12 m/s^2 (6.0 mm) and 2.44 m/s^2 (7.0 mm). The noise was broadband (range 0.2 to 16.0 kHz) A-weighted stable noise, the intensity of which was set at 90 dB. During the experimentation period other environmental factors were held as constant as possible.

Changes in the upright body sway were examined using a new kind of a body sway measuring device based on the use of a microprocessor. Changes in body sway were estimated by measuring the motion of the center of gravity in the directions y and x. Body sway measurements were carried out twice during the control period, once during each 16-minute exposure period and once during the 15-minute recovery period. The measurements were made about three minutes after exposure. Before the analysis of the results the values obtained in the sway measurements were corrected so that the values obtained after the second control period were deducted from the values measured after the exposure and recovery periods.

The measuring platform of the stabilometer was positioned in the exposure chamber in such a way that during the measurements the subject faced a wall. Given a signal, the subject stood up from the vibration chair and took a standing position on the load cells of the measuring platform. On the measuring platform the subject, stood with his heels pressed together, his feet outwards at a angle of 30-degrees, his back straight, his hands loosely pressed against his thighs and his eyes closed. Besides keeping their eyes closed during the measurements, the subjects wore goggles that completely blocked out all light.

In order to make the position of the head and body uniform a line was marked on the wall of the exposure chamber at a suitable height. The subject was asked to imagine that while standing on the measuring platform he was looking at this marking line despite the closed eyes and goggles. The sway measurements were carried out under the supervision of the researcher after the subject had taken up the position described above. The subject stood on the measuring platform for about 70 seconds, the signals of the first 10 seconds being omitted. Actual sway analyses were thus made on the basis of a 60-second sample.

RESULTS

In this report the size of the changes in the stability of the upright body posture has been characterized with the aid of arithmetic means of maximum amplitudes. Each subject's greatest sway amplitude was determined within the frequencies 0.06-0.10 Hz and 0.10-0.60 Hz in connection with every measurement. These results have been presented in Tables 1 and 2.

In the x direction, the maximum amplitudes of sway (i.e. sway of upright body posture) within the frequency range 0.06-0.10 Hz increased more when the subjects were simultaneously exposed to noise and vibration. The means of the amplitudes within this frequency range increased consistently from one exposure period to another when the combinations of noise and vibration included vibration at an amplitude of

Table 1. The differences of arithmetic means of maximum amplitudes of upright body posture sway within the frequency ranges 0.06-0.10 Hz and 0.10-0.60 Hz in the x direction by different exposure combinations and order of exposures (n=10). The values have been adjusted in relation to the control values obtained before the exposure period.

Exposure combination	Amplitudes 1st exposure a[1)]	b	2nd exposure a	b	3rd exposure a	b
No noise, no vibration	-3.8	- 8.7	-16.6	-19.8	- 9.0	- 3.7
90 dB(A)	6.2	11.0	- 3.9	19.0	- 4.2	- 1.1
5Hz(2.12 m/s^2)	-5.4	- 6.4	4.7	- 7.9	- 3.3	-14.8
5Hz(2.44 m/s^2)	1.6	0.4	7.3	- 2.9	- 0.7	- 1.8
90 dB(A)+5Hz(2.12 m/s^2)	4.0	14.6	4.8	11.2	10.1	15.6
90 dB(A)+5Hz(2.44 m/s^2)	2.9	- 7.6	1.0	- 0.9	8.5	9.0

1) a = frequency range 0.06-0.10 Hz; b = frequency range 0.10-0.60 Hz

Table 2. The differences of arithmetic means of maximum amplitudes of upright body posture sway within the frequency ranges 0.06-0.10 Hz and 0.10-0.60 Hz in the y direction by different exposure combinations and order of exposure (n=10). The values have been adjusted in relation to the control values obtained before the exposure period.

Exposure combination	Amplitudes 1st exposure a[1)]	b	2nd exposure a	b	3rd exposure a	b
No noise, no vibration	- 3.7	-27.0	-14.2	-35.2	- 9.4	-37.9
90 dB(A)	- 3.5	5.6	- 4.0	4.1	-10.1	- 6.8
5Hz(2.12 m/s^2)	-16.2	- 2.2	- 3.3	23.9	- 9.7	14.7
5Hz(2.44 m/s^2)	- 4.8	- 4.9	- 9.7	- 2.9	-14.3	-11.8
90 dB(A)+5Hz(2.12 m/s^2)	19.1	11.7	19.0	14.5	- 4.7	10.4
90 dB(A)+5Hz(2.44 m/s^2)	- 4.4	- 7.8	25.3	16.9	17.9	3.2

1) a = frequency range 0.06-0.10 Hz; b = frequency range 0.10-0.60 Hz

7.0 mm. Within the frequency range 0.10-0.60 Hz the means of sway amplitudes increased significantly after the first and second exposure due to noise alone and after every three exposures due to simultaneous noise and vibration. In this case, too, the amplitude of the vibration of the exposure combination in question was 7.0 mm.

In the y direction, within the frequency range 0.06-0.10 Hz, the means of the maximum amplitudes compared with the control values were considerably larger than under exposure to simultaneous noise and vibration. Sway in the y direction also seemed to increase as a result of noise alone and vibration alone in the frequency range 0.10-0.60 Hz.

CONCLUSIONS

The results show that a relatively short-term exposure to noise alone or to vibration alone may affect the stability of the upright body posture. However, the instability of the upright body posture increases significantly when noise and vibration of an exactly equal kind affect the subject simultaneously. When the exposure is repeated, the changes in sway seem to become intensified.

Because noise and vibration are very common in modern work environments, the observations described have obvious significance with regard to labor protection, for example.

The results conform with those obtained by the German researchers Seidel et al. (1980), because in the present study, as in the German study, the changes in sway are distributed in such a way that the sway is greatest within the

lowest frequency ranges. Interpretation of this observation is not easy, however. Van Eyck (1974) has proposed that, for example, injury caused by noise does not concern only the cochlea but also the balance system. A tentative explanation for this is that the cochlea and the vestibular structures are very close to each other (Cohen, 1977). In the opinion of Parker et al. (1968) it is impossible for noise energy to bypass the vestibular receptors. Simultaneous acoustic and vestibular stimulation is undoubtedly an indication of close interaction between the hearing and balance systems, and depending on the exposure situation, both stimulation routes may come into question (Myer et al, 1971). For this reason, the combined effects of simultaneous noise and vibration on the different functions of the organism and, for instance, on low frequency changes in body sway, may be more intensive than the individual effects of the same factors.

Regulation of the stability of the upright posture is a complex physiological phenomenon. Partly because of this complexity and partly because of the scarcity of sway measurements based on frequency analysis, researchers today are not unanimous, for example, about the best parameter to describe upright posture sway. Additional research is therefore necessary. In addition to comparison of the different parameters describing sway and the examination of sinusoidal vibrations we should in particular study stochastic vibrations and longer exposures.

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ACKNOWLEDGEMENTS

The Medical Research Council of the Academy of Finland has financially supported this research program. I wish to express my thanks to Veikko Ritvaniemi, Ari Ekblom and Ritva Manninen for the great help they have given me.

A REVIEW OF EXPOSURE COMBINATIONS INCLUDING NOISE: THE MEANING OF COMPLEX EXPOSURES

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In the past few years doubts have arisen in many countries about the reliability and applicability of the results of isolated instrumental measurements of factors related to environmental hygiene. These doubts are due, for instance, to the fact that these measurements have not led to any significant change in the theories about the connection between morbidity and occupational status. According to the conclusions drawn from this, the health hazards in question are not caused by variations in the intensity of individual environmental factors; the health hazards are, in fact, combinations of the physical, chemical, biological and psychosocial factors which characterize the circumstances in question.

The same kind of thinking is reflected in the literature in claims that the combined effects of environmental factors on the organism are greater than the independent effects of individual environmental factors: For instance, "one environmental stress adds to the intensity of another in such a way that the combined effect is greater than the sum of stresses" (74) or "hazards, whether chemical, physical, biological or stress, often combine in such a way that their effects are not merely additive but synergistic" (4). For instance, the leading role in the aetiology and pathogenesis of occupational diseases may not be played by different kinds of hazards of low intensity but instead by the combined effects of these hazards (72).

In real life, describing combined effects is in no way this easy and simple. In spite of their importance, the combined effects of the different kinds of environmental factors are still, to a large extent, an unexplored area of research. The lack of research in this area may partly reflect the ways researchers approach problems, and partly the many difficulties faced by the researcher in his work. In general, we might say that the more combinations of environmental factors are studied, the more complex and refined is the measuring system required and the more laborious, expensive and time-consuming the research work is. Increasing the number of factors to be studied increases exponentially the need for the various resources required to study their combinations.

Although existing knowledge of the onset and developmental mechanisms of diseases with many aetiologies is deficient, and despite the obvious difficulties involved, it seems justified to aim at simultaneous examination of the details of several factors. This approach is worth considering because of the large number and versatility of the factors present in traffic and practical work situations. The study results referred to in this review also provide good reason for the research line suggested here.

Noise can be regarded as one of today's worst and most common environmental pollutants. Noise, however, does not usually occur alone in an environment; other environmental factors or factors related to work are almost always connected with it. The study of the combined effects of noise and various other environmental factors is therefore justified.

CHANGES IN THE HEARING THRESHOLD

Field studies. Deterioration of hearing is the best known of the many harmful effects of noise. However, as early as 1960, both Rahmilevits (91) and Temkin (105) found that pathological changes in hearing were exacerbated by concomitant vibration. For example, Temkin pointed out that a relatively large proportion of the disturbances in cochleovestibular functioning in steel fixers were caused by the vibration and noise caused by the equipment with which they worked. Parallel observations on accelerated deterioration in hearing have since been made in many fields, in particular among persons who are compelled to use machinery and equipment causing noise and vibration in their daily work. Apart from construction sites, simultaneous occurrence of noise and vibration and its consequences have been studied at least in mines (104), metal and coachwork factories (23, 54, 58, 62, 81, 86, 96), locomotives (80), weaving mills (93, 103, 108), foundries (54, 96), tractors (9, 85, 95), ships (8), forestry work (88, 89) and helicopters (15). In the study situations the noise level has ranged from 90 to 113 decibels and vibration frequencies from 1 to 50 Hz.

Laboratory tests with human subjects. The results of the many laboratory tests with human subjects show that simultaneous noise and vibration cause a considerably greater elevation in the hearing threshold than vibration alone (3, 69, 75, 79, 114, 116). In these studies subjects have been mostly exposed to vibration of the whole body and stable noise in the sitting posture. According to a report published last year the effect of the permitted vibration parameters would also increase the harmful effects of impulsive noise (102). Depending on the frequency, the additional effect of vibration varied from 8 to 33 per cent. Apart from the authors above mentioned, Guignard and Coles (30)[1], and Sommer (99), have observed no combined effect of noise and vibration on the TTS values.

Ratner and Zvereva (92) are of the opinion that an exposure combination consisting of noise, elevated environmental temperature (33-35 °C), medium-heavy physical work and vibration would lead to greater changes in the hearing threshold than exposure to noise alone.

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[1] An unusual and significant feature in Guignard's and Coles's study was that the hands of the subjects were placed on the knees and the feet of the subjects on a non-vibrating footrest.

The results of the tests carried out by myself in a special exposure chamber (60) show that the combined effects of stable noise and sinusoidal vibration of the whole body are most obvious when the noise spectrum includes the frequency ranges 1-4 kHz, 1-8 kHz or 0.2-16 kHz (65). The changes occur primarily in the 4 kHz to 6 kHz range. During simultaneous exposure to broad band (width of band 0.2-16 kHz) noise of 85 dB(A) and 98 dB(A) and 5 Hz vibration, in particular the TTS_2 values around 4 kHz increased by an average of 1.2-1.5 times more than during exposure to noise alone. The results of another test showed that the means of the changes in the temporary hearing thresholds at a dry bulb temperature of 30°C were larger than at 20°C (66). Environmental temperature became increasingly important during consecutive exposure periods (Figure 1). The effect of temperature was particularly clear when a noise of 95 dB(A) was included in a paired noise and vibration combination. On the basis of the tests involving dynamic muscular work (63) on the part of the subjects it could be observed that the combined effect of 90 dB(A) broad band stable noise and 5 Hz vibration on the TTS_2 values at the 4 kHz hearing frequency was especially clear when the subjects worked at an efficiency of 2 Watt at dry bulb temperatures of either 20°C or 30°C. In connection with four times more strenuous work (8 W), noise and vibration could not be found to have a corresponding effect, and did not cause an

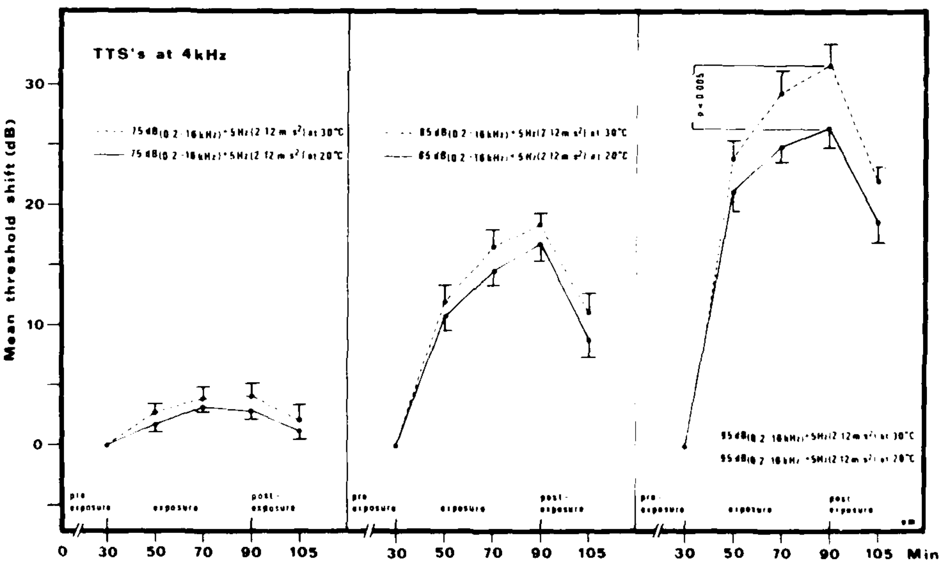

Figure 1. Arithmetical means of the temporary hearing threshold (TTS_2) and half of the standard error of the mean at the frequency of 4 kHz for different exposure combinations. During the test the subjects switched off lights appearing on a lamp panel with the fingers of their right hand. The curves have been drawn using the results of 20 ears.

acceleration in the increase in the hearing threshold. At a temperature of 30°C, the behaviour of the TTS_2 values in the hearing frequency of 6 kHz, and especially 8 kHz, even seemed to be contrary to the above.

The additional effect of vibration in causing an increase in the hearing threshold was particularly clear when the vibration was stochastic and the subjects worked at a low efficiency (64). According to the results of variance analysis, the combined effect of all three factors (noise, vibration and work) on the TTS_2 values (after three 16-minutes exposure periods) was significant at the 2.5 % level at the 4 kHz hearing frequency and significant at the 5 % level at the 6 kHz hearing frequency.

Laboratory tests with animals. Many tests carried out with rats, rabbits, mice and guinea pigs show that noise and vibration, when they occur simultaneously, have a more harmful effect on the hearing organ than noise alone (6, 32, 35, 71, 84, 115). Combinations of whole body vibration and impulse noise exposures can lead to a severe potentiating effect (13).

Haider (33) has described the combined effects of chemical factors on hearing. In addition, some new observations concerning the effects of combinations of certain medicines, smoking or individual background factors and noise can be found in a series of monograms published last year (37). According to Zeigelschäfer (117) and Zorn (118), the effects of noise and carbon monixide accumulate, while Austrian researchers ([illegible]) did not find carbon monoxide (200 ppm) and noise (105 dB) to have a statistically significant combined effect on TTS values. (It is interesting, however, that significant hearing deficiencies (i.e. 40 dB or more in the 4 kHz area) would seem to be more common and greater among smoking male subjects than among non-smoking male subjects (98)).

CHANGES IN SWAY IN THE UPRIGHT POSTURE OF THE BODY

According to the literature, stability in a standing person reflects the functional state of the vestibular analyser and is one of the basic criteria of the functional state of the central nervous system (31).

Besides being responsible for an increase in the hearing threshold, exposure to noise or vibration has been discovered to cause dizziness and other equilibrium disturbances (53, 78). The connection between the degree by which the hearing threshold of those who are exposed to vibration and noise in their daily work increases with a simultaneous impairment of balance regulation would seem to refer to this: the higher the environmental index point score depicting the harmful effects of simultaneous noise and vibration, the poorer the hearing and the poorer scores the subjects achieved in tests measuring the functioning of the sense of balance ([illegible]). According to Korol (50), loud process noise affects the sensitivity of the vestibular system. Under simultaneous exposure to noise and vibration the harmful changes are more obvious than under exposure to noise alone.

In connection with low-frequency vibrations in particular, the effects of noise and vibration and the channels along which such effects move in the organism may be practically the same (29, 106). This is permitted by the close juxtaposition of the cochlea and the vestibular structures ([illegible], 71). According to Parker (84) it is impossible, in fact, for sound energy to bypass the vestibular receptors (e.g. the saccula) and affect the central nervous system directly. This also appears in Figure [illegible], which

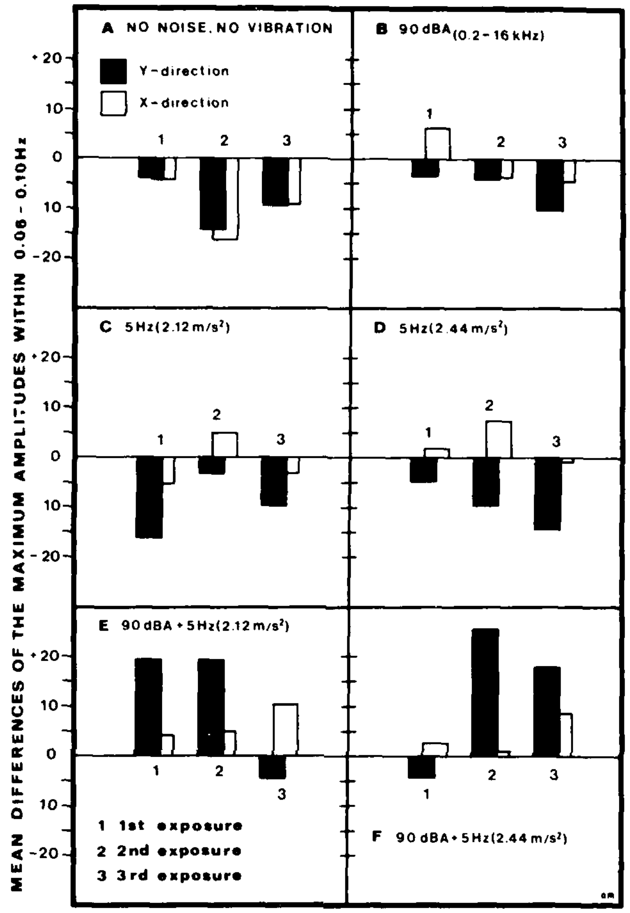

Figure 2. The means of the maximum amplitude of body upright posture sway in the directions y and x. The means were adjusted with the pre-exposure rest values and were computed on the basis of the results of sway measurements on 10 subjects. The test design and measuring equipment have been briefly described elsewhere (20, 67).

shows the results of some stabilometer measurements (67). The method involved assessment of changes in body upright posture stability by measuring changes in the center of gravity in directions y and x. In general, it can be said that the changes in the · imum amplitudes of sway occurred at low frequencies and that lateral sway (direction y) was more intense than sway in the back-breast direction (direction x). The maximum amplitude of average sway (y-direction) in the left-right side direction increased significantly more than the pre-exposure rest values in the frequency range of 0.06-0.10 Hz when the subject had been simultaneously

exposed to both broad band 90 dB(A) noise and vibration of the whole body (Figure 2E, F). Preliminary observations would also seem to indicate that the increase in sway as a result of combined noise and vibration and the increase in the hearing threshold are correlated.

CARDIOVASCULAR CHANGES

Some study results show that, in connection with mentally and physically strenuous work, noise may accelerate the heart rate (48, 90, 100, 101). A contrary observation has been made by Finkelman and his colleagues (22), who maintain that 90 dB noise and physical work on a bicycle ergometer do not have an additive effect on the heart rate of the subject.

The combined effect of simultaneous noise and neuropsychic tension on both the systolic and diastolic blood pressure is greater than the isolated effect of either factor (97). According to Dresen and Borhols (17), 90 dB(A) noise recorded in a textile factory increases the diastolic blood pressure, but if muscular work is simultaneously combined with noise, the effect of muscular work dominates over the effects of noise. As far as the direction of the resultant reaction is concerned, noise and vibration differ slightly from each other; when noise and vibration are applied together, the nature of the reaction corresponds to that caused by vibration, although its volume is somewhat reduced (82). German researchers (39) have shown that as a result of simultaneous exposure to noise and vibration of the whole body, diastolic blood pressure hardly changes at all, while the heart rate, systolic blood pressure, breathing frequency and oxygen intake increase. A helicopter flight simulated in the exposure chamber, including an exposure to noise and vibration, did not, however, weaken the performance of the pilots or change their physiological activities (15).

The results of the tests I have carried out show that noise and vibration occuring separately at a temperature of 20°C, have almost opposite effects on the heart rate variations, whereas at a temperature of 30°C the separate effects of noise and vibration are parallel, i.e. they increase the heart rate (Figure 3). After the third exposure to paired noise and vibration combination, however, there was a reduction in the heart rate, but the reduction was slightly larger at 20°C than at 30°C. The means of the R-wave amplitudes were systematically smaller at 30°C than at 20°C. The differences in the behaviour of the R-wave amplitudes were apparent especially with an increase in the intensity of noise in the combination. When the subjects were exposed to 85 dB(A) noise alone, diastolic blood pressure increased very conspicuously at both 20°C and 30°C. The means of systolic blood pressure, again, diminished without exception during all exposure periods after exposure to noise alone, vibration alone or combinations of noise and vibration when the exposure chamber temperature was 30°C.

BIOCHEMICAL CHANGES

Determining the subject's creatine kinase activity is a useful way of assessing the intensity of exposure to noise and vibration (46). During physical work the effects of noise and vibration are also manifested as an increase in the activities of serum aldolase and lactic dehydrogenase (25). The blood sera of workers exposed to severe acoustic and vibrational

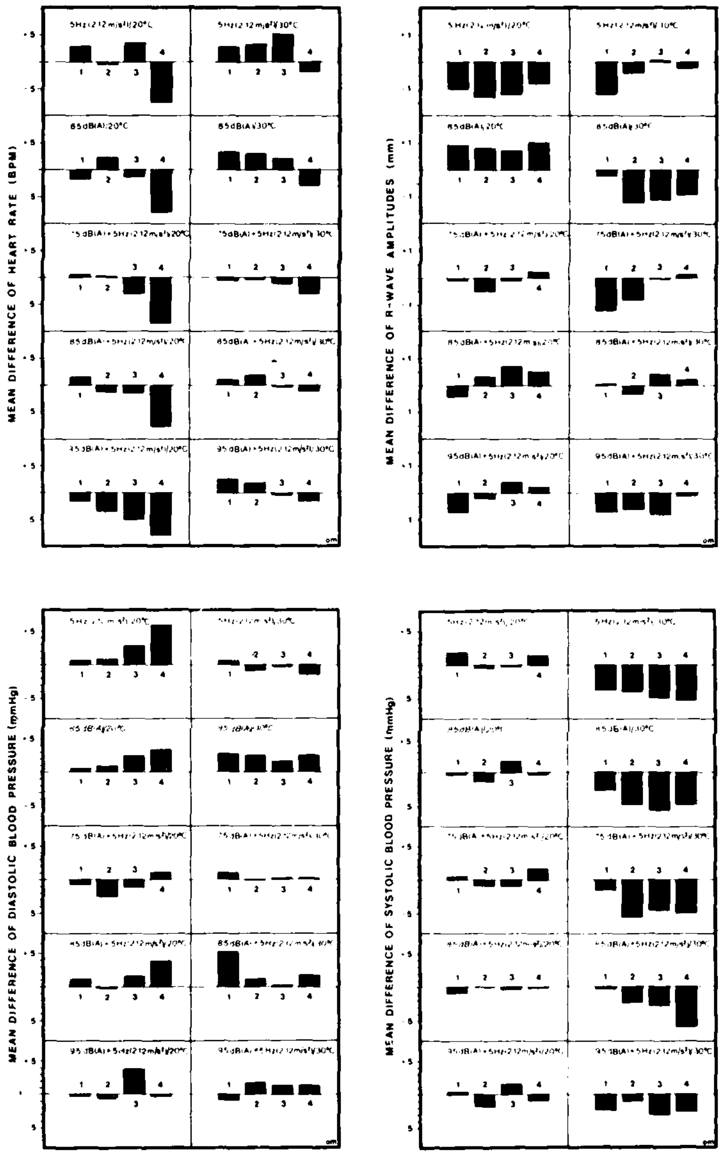

Figure 3. *Average changes in heart rate, R-wave amplitude,* diastolic blood pressure and systolic blood pressure in subjects (n=11) exposed separately and simultaneously to broad band noise and sinusoidal vibration of the whole body along vertical direction (Z axis) at dry bulb temperatures of 20°C and 30°C. During the test the subjects switched off lights appearing on a lamp panel with the fingers of their right hand. Number 1 = 1st exposure values, 2 = 2nd exposure values, 3 = 3rd exposure values, and 4 = post-exposure values.

stimuli revealed decrease in protein level and quantitative in protein fractions (24).

A larger and more frequent retardation in the erythrocyte sedimentation reaction (ESR) is detected more often and to a greater extent among those who work in noisy surroundings than among those exposed to vibration in their work (28). On the other hand, the haemoglobin content and erythrocytes increased after exposure to carbon monoxide alone. Under exposure to noise alone or a combination of noise and carbon monoxide, peripheral blood reacts in the opposite way, i.e. it becomes anaemic (117). Experiments on male white mice showed that total vibration and the accompanying noise enhance the development of poisoning with carbon monoxide (51). On the other hand, the combined effect of noise and acetone is less than additive, if not antagonistic (10).

A greater reduction in the liver respiration of rats was observed under the combined action of noise and acrylonitrile (73). A synergistic action was observed for the enzymes glutamate puryvate transaminase, glutamate oxalacetate transaminase and fructose -1.6-diphosphate aldolase (40). Verzilova et al.(109) indicate the necessity of introducing certain amendments aimed at decreasing the maximum permissible concentration of benzene and the maximum permissible level of vibration and noise in case of their prolonged joint action. In addition to these, very marked changes in hormonal excretions and vegetative functions have been found among subjects under complex exposure conditions (2, 48, 52, 59, 62, 83).

CHANGES IN BODY TEMPERATURE

Vasoconstrictions in peripheral blood circulation are possible not only under exposure to noise but also under local exposure to vibration only (49). Changes caused by simultaneous exposure to noise and vibration are parallel with the changes caused by vibration alone (19). In suitable combinations the effects of noise, vibration and temperature may be cumulative, perhaps additive (7). Grether et al. (27) found that the skin and rectal temperatures of the subject drop during exposure to 5 Hz vibration, in particular, but also during simultaneous exposure to vibration and noise. The results I have obtained in equivalent tests are similar.

Temperature differences increased (deep body temperature decreased) systematically after exposure to all combinations of noise and vibration at a temperature of 20°C. The average sublingual temperature differences were the largest, however, when the subjects were exposed to vibration alone (Figure 4A). Their temples cooled fastest (average difference -0.87°C) when subjects at a dry bulb temperature of 20°C were exposed to simultaneous vibration and 95 dB(A) noise (Figure 4B).

When the nature of the task was changed by including dynamic muscular work in the exposure combinations, temperatures at the temples changed in an interesting way. Working at dry bulb temperatures of 20°C and 30°C at an efficiency of 2 W, the average differences in temperatures at the temples were, as a rule, smaller than the values obtained while working at an efficiency of 8 W (Figure 4C). Metatarsus surface temperature in the right foot dropped most (-2.1°C) when the subjects carried out light work (2 W) and were simultaneously exposed to noise and vibration at a temperature of 20°C. Foot instep temperature was at its highest when work was carried out at an efficiency of 8 W and 2 W under

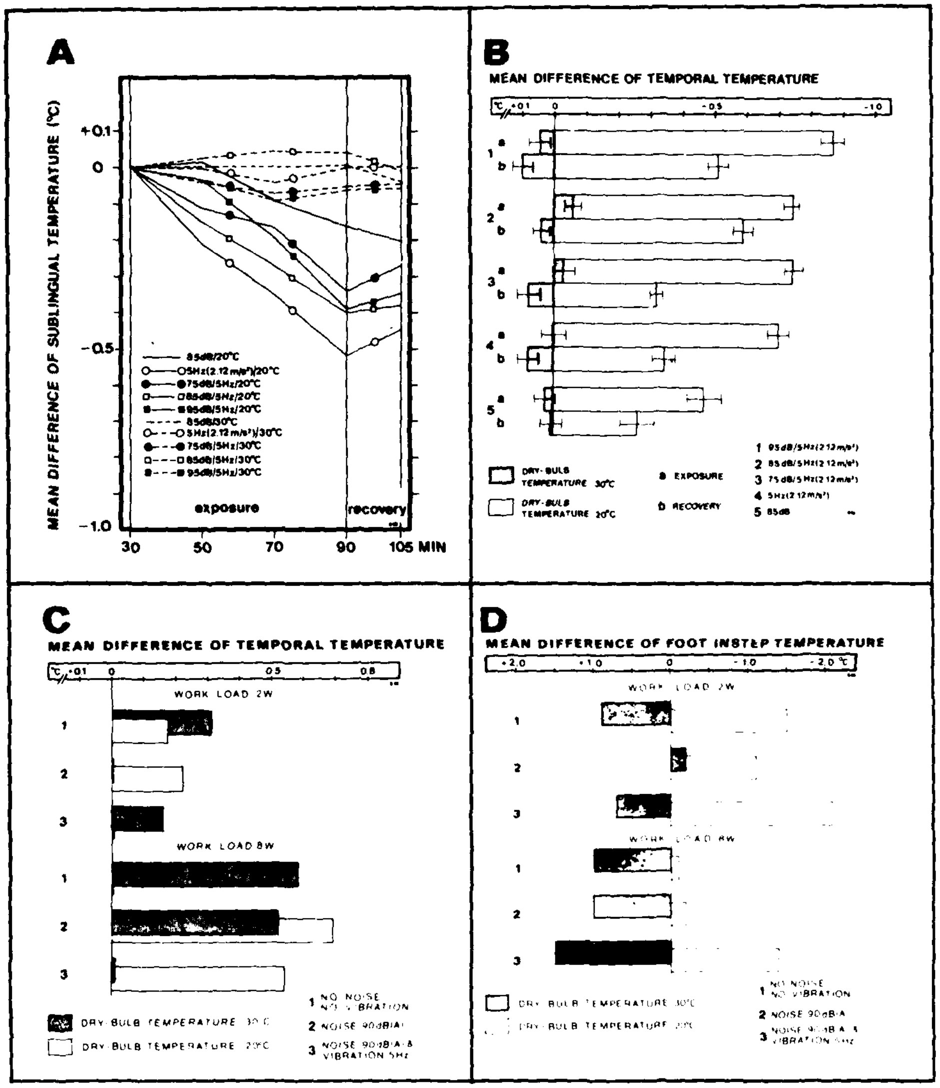

Figure 4. Average differences in (A) sublingual temperature and (B) temporal temperature (°C) caused by exposure combinations in the test, in which the subjects (n=11) switched off lights on a lamp panel with fingers of their right hand. Average differences in (C) temporal temperature and (D) metatarsus skin temperature of the right foot caused by exposure combinations in the test, in which the subjects (n=72) carried out dynamic muscular work. The values have been obtained by deducting the temperatures of 30 minute control period from the values of the third exposure values and recovery values (i.e. Figures 4B,C,D).

exposure to noise and vibration at a temperature of 30°C, and it was, in fact, higher than the values obtained after exposure to noise alone (Figure 4D).

THERMAL COMFORT

The main principle underlying thermal sensations is that dilation of the peripheral blood vessels causes a sensation of warmth, and constriction of the peripheral blood vessels causes the sensation of cooling. As Dean et al. (14) summarised, noise may alleviate discomfort due to heat, either through constriction of peripheral blood vessels or suppression of pain. In one of their studies the Danish researchers (21) did not, however, find that a noise of 45 dB(A) or 85 dB(A) essentially affected the thermal comfort of the subjects.

Table 1 contains thermal sensation assessment scores and corresponding temporal and sublingual temperature values measured after different exposure combinations. In the test, the subjects assessed their subjective thermal sensations on the following scale: 1 = hot, 2 = warm, 3 = comfortable, 4 = cool and 5 = cold. The table shows that after exposure to noise alone the subjects on the average assessed their thermal sensation to be cool (4), while after two exposures to vibration their thermal sensations fell between comfortable and cool.

In another test designed to obtain information about the significance of elevated environmental temperature from the point of view of the activities of the organism the subjects were asked to assess their thermal sensation on a different scale from that used in the previous test. On this scale the verbal expression "very hot" corresponded to number 1, "hot" to number 2, "rather hot" to number 3, "warm" to number 4 and "comfortably warm" to number 5.

The results of the 3-way variance analysis showed that after the second consecutive exposure period (duration about 40 minutes) work was the only one of the studied parameters which had a significant main effect

Table 1. Arithmetical means ($\bar{X}$) and standard deviations (sd) of subjective thermal comfort assessments, sublingual temperatures, and left-hand temporal temperatures after the third consecutive exposure period and the recovery period. The subjects [illegible] had been exposed to combinations of noise and vibration. The test was based on a block design. During the test the average dry bulb temperature in the exposure chamber was 19.8°C, the average radiant temperature [illegible], the relative humidity 43 %, and the illuminance of general lighting 300 lux. During the test the subjects wore standard clothes.

Exposure combination	Third Exposure values ThC $\bar{X} \pm sd$	ST $\bar{X} \pm sd$	TT_L $\bar{X} \pm sd$	Post-Exposure values ThC $\bar{X} \pm sd$	ST $\bar{X} \pm sd$	TT_L $\bar{X} \pm sd$
No noise, no vibration	3.9±0.7	-0.2±0.1***	-0.3±0.3*	3.8±0.8°	-0.3±0.2	-0.3±0.4
[illegible] dB(A)	4.0±0.5**	-0.2±0.2**	-0.3±0.4	3.9±0.7	-0.3±0.4	-0.3±0.5
5Hz (2.12 m s^{-2})	3.5±0.5	-0.4±0.2***	-0.5±0.4	3.6±0.5	-0.3±0.2	-0.3±0.2
5Hz (2.44 m s^{-2})	3.4±0.5**	-0.5±0.4	-0.6±0.4*	3.5±0.5°	-0.3±0.2	-0.4±0.4
[illegible] dB(A)+5Hz (2.12 m s^{-2})	3.8±0.4**	-0.4±0.3**	-0.7±0.6*	3.9±0.6*	-0.4±0.4	-0.5±0.5
[illegible] dB(A)+5Hz (2.44 m s^{-2})	3.7±0.5	-0.4±0.4	-0.7±0.4*	3.6±0.5	-0.3±0.2	-0.4±0.5

ThC = Thermal Comfort, ST = Sublingual Temperature, TT_L = Temporal Temperature

*** $p < 0.001$, ** $p < 0.005$, * $p < 0.05$, ° $p < 0.10$

Table 2. Means ($\bar{X}$) and standard deviations (sd) of thermal assessments by exposure combinations and exposure periods. The test design was that of a 3-2-3 factor analysis, and the number of healthy male subjects was 90. During the test the average dry bulb temperature in the exposure chamber was 30.1°C, the average radiant temperature 30.2°C, the relative humidity 53 %, and the illuminance of general lighting 300 lux. During the test the subjects carried out dynamic muscular work with the muscles of their right hand. The load of work was regulated with a double-acting pneumatic cylinder system and related non-return throttle valves. The work had two cycles so that the actual work was done while the handle at the end of the pneumatic cylinder was pulled toward the body and the rest cycle followed when the handle returned to its point of departure. The working tempo was controlled with the aid of the lights glowing on a panel in the choice reaction apparatus. Rating scale: 1 = very hot, 2 = hot, 3 = rather hot, 4 = *warm*, and 5 = *comfortably warm*.

Vibration level		Work load 2 W Noise level: No noise $\bar{X}\pm$sd	2 W Noise of 90 dB(A) $\bar{X}\pm$sd	4 W No noise $\bar{X}\pm$sd	4 W Noise of 90 dB(A) $\bar{X}\pm$sd	8 W No noise $\bar{X}\pm$sd	8 W Noise of 90 dB(A) $\bar{X}\pm$sd
No vibration	1[1]	2.4±0.5	3.0±0.7	3.0±1.0	3.0±1.0	2.8±0.8	2.4±0.9
	2	2.4±0.9	3.4±1.1	2.8±0.8	3.0±1.2	2.2±0.4	2.8±0.8*
	3	2.4±0.9	3.0±0.7	3.0±0.7	3.0±1.2	2.0±0.7	2.8±1.3
	4	3.2±1.3	4.0±1.0	4.6±0.5	4.4±0.5	3.4±0.9	4.4±0.5
Vibration frequency of 5 Hz (2.12 m/s²)	1	3.2±1.3	3.2±0.8	3.0±0.7	2.6±0.5	2.8±0.4	2.6±1.1
	2	3.2±1.1	2.6±0.9	2.8±0.4	3.0±1.0	1.8±0.8	2.8±0.8*
	3	3.0±0.0	2.8±0.8	3.2±0.8	3.0±1.0	1.8±0.8	2.4±0.5**
	4	4.0±0.7	3.8±0.4	4.0±1.0	3.6±0.5	4.6±0.5	4.0±0.0
Vibration frequency of 2.8-11.2 Hz (2.12 m/s²)	1	2.8±1.3	3.0±1.0	3.6±0.5	2.8±1.1	3.0±1.0	1.8±0.8
	2	2.6±0.9	2.6±1.3	*3.6±0.9	2.4±0.5*	*3.0±1.0	1.6±0.5*
	3	2.8±0.8	3.0±1.0	3.4±0.9	2.4±0.9	2.6±1.[illegible]	1.4±0.5**
	4	4.2±1.1	3.8±0.4	4.2±0.4	3.2±1.6	4.8±0.4	4.2±1.3

[1] 1 = 1st Exposure, 2= 2nd Exposure, 3 = 3rd Exposure, 4 = Post-Exposure, **p < 0.025, *p < 0.05

(F-value = 3.20; df = 2,72; $p < 0.05$) and noise and vibration the only ones which had a significant combined effect (F-value = 5.24; df = 2,72; $p < 0.01$) on variations in thermal sensation. After an hour's exposure, work still had the most significant main effect and noise and vibration a significant combined effect on thermal sensations.

Examination of the means of the thermal sensation assessments show that the subjects felt warmest (between very hot and hot) more after work of 8 W and simultaneous exposure to noise and stochastic vibration than with all other exposure combinations. On the other hand, noise seemed to increase the sensation of heat under exposure to stochastic vibration and medium-heavy (4 W) and heavy (8 W) work loads (Table 2).

This is one example of the different psychophysiological effects of varying noises and vibration under complex exposure situations (to which I have already referred in another article on the subject of heart rate (68)).

VARIATIONS IN THE ASSESSMENT OF DISCOMFORTS DUE TO NOISE

Noise and vibration are very often described as environmental hazards which are so similar to each other (45) that people are unable to distinguish between the effects of noise and vibration (11). The presence of either factor may thus affect the assessments of the degree of discomfort of the other factor (38), and according to Kirby et al. (47) a confusion like this would be possible at low stimulus levels, in particular. At high stimulus levels the validity of the assessments would increase, since the noise and vibration components would be assessed separately. Grether et al. (27) found that subjective assessments were systematically dependent on the number of factors included in combinations of discomforts. According to some researchers, subjective assessments are always biased to a certain extent (87).

It seems to me that the basic question is what is the most valid method by which the validity of subjective assessments could be measured. Certain observations indicate that the other working environment discomforts, the presence of which can be verified through the senses, do not to any essential degree affect the assessment of the discomforts caused by noise and light (55). The assessments concerning the annoyance caused by the working environment factors also proved to be satisfactorily constant, since the correlation coefficients between repeated measurements varied between 0.66-0.68 (draught) and 0.87-0.91 (noise). The correlation coefficients between noise assessments made by subjects and equivalent noise levels measured in the working environments varied from 0.71 to 0.85. The highest correlation coefficients were obtained when calibrated rating scales were used (57).

Figure 5 shows the regression equations obtained at environmental noise levels for two rating questions. The slope of rating scale R1 is somewhat steeper than that of rating scale R7. This comparison gives a variance of estimations which, translated into an equivalent range of noise exposure, has a maximum fluctuation of the order of 5 dB between the rating results. From a practical point of view and for corrective purposes or transformations from one scale to another an established association of this kind is obviously meaningful.

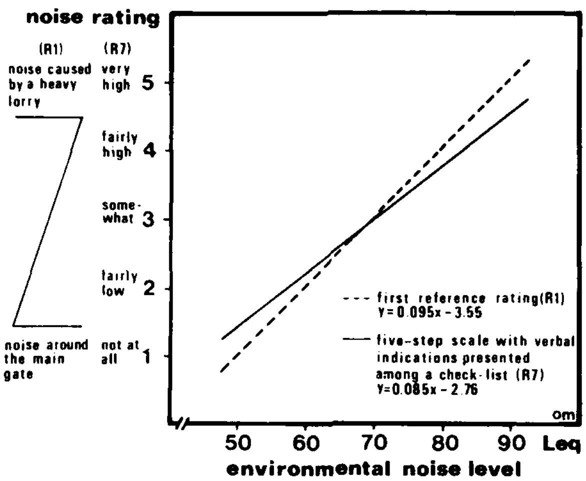

Figure 5. Comparison of the first reference rating (R1) to the five-step scale with verbal indications of degrees of discomfort presented in a check-list (R7) as a function of computed equivalent noise level (Leq). Regression analyses were done using a linear regression model (n=60).

ENVIRONMENTAL INDICES

As can be concluded from the foregoing remarks, many problems are related to the ways in which environmental health and comfort are depicted. I will elucidate these problems with another example based on the results of a questionnaire study carried out a few years ago (56).

Knowing that the comparison and combination of the hazardous effects of the different environmental factors causes problems, I have included Figures 6A and 6B to show the index of hazardous energy distributions and the index of discomfort from pollutants present in breathing air. The index of hazardous energy distributions has been formed by summing up discomfort assessment scores related to noise, vibration, light and thermal conditions. The index of discomfort from the pollutants of the breathing air includes miscellaneous discomforts such as paint fumes, stone or sand dust, soot, ashes, metal dusts or fumes, smoke or gases.

I want to draw the reader's attention to the manner in which these indices were built up. The point of departure in considering the structure of the index is the principle that an index depicting environmental conditions must not be composed merely of the sum or mean of its components. This could also be applied to studies of the standard of living, for example. If there is only one single environmental factor which causes much or very much discomfort, the discomfort in question will not diminish through simultaneous scrutiny of factors causing less discomfort.

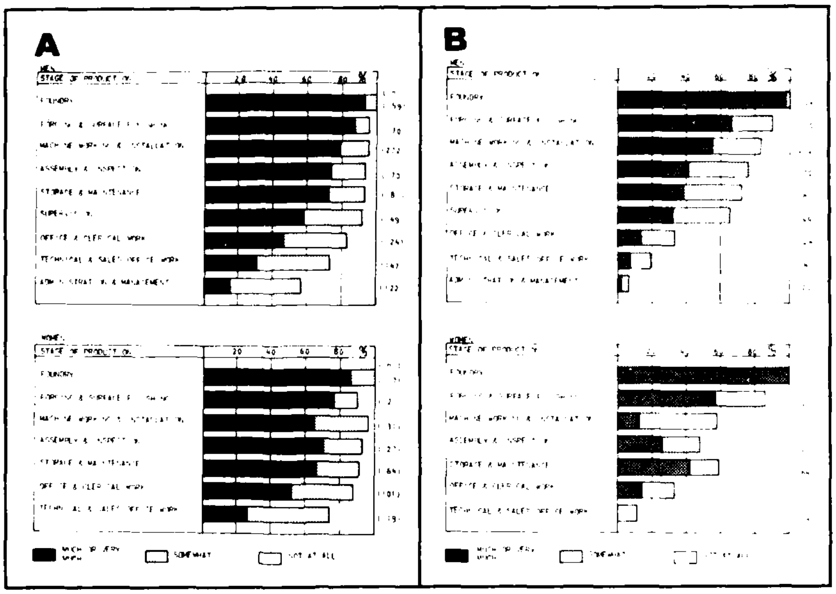

Figure 6. Combined effect of hazardous energy distributions in working environments according to (A) the index of discomfort from physical factors, and (B) the combined effect of chemical substances in the breathing air of the same workplaces according to the index of discomfort from the pollutants of the breathing air by stage of production.

The indices were formed on the basis of the arithmetical mean of the item scores, subject to the following class limits and further conditions:

Index points	Class limits of means	Degree of discomfort
1	0.0 - 1.0	not at all
2	1.1 - 1.6	somewhat
3	1.7 - 2.0	much
4	2.1 -	very much

A further condition was that 4 points was allocated to a variable scoring 4 or several variables scoring 3. If one variable scored 3, the number of index points was likewise 3.

The index points calculated in this manner varied by stages of production of engineering industry with a certain regularity. The highest index points were recorded in primary production (Foundry) and the number of points diminished gradually via the production stages to the category Administration and management. The figures show conclusively that various

kinds of hazardous energy and respired air impurities occur simultaneously in people's working environments.

CHANGES IN WORK PERFORMANCE

Environmental noise and heat have the greatest effect on work tasks which require a minimum of mental effort and motivation (77). Unstable noise, in particular, combined with an environmental temperature of 28-30°C, and work causing little stress has a more harmful effect on man than noise alone (119).

In the combined stress condition, heat reduced the detrimental effects of noise, and noise removed the beneficial effect of heat on the control task (112). These observations by Wyon suggest that noise and heat stress increase arousal while comfortable warmth reduces arousal. Bell (5) states that performance decrements associated with high noise levels and high ambient temperatures are additive for the subsidiary task. Exposure to a combined noise-plus-vibration stimulus causes more profound and persistent changes in the ability to do mental work than exposure to sound alone (43).

CONCLUSIONS

Surveys of the results of studies dealing with combined effects have already been prepared at least by Grether (26), Schmidt (94), Murray and McCally (76), Dupuis (18), von Gierke (110), Menshov et al. (70) and WHO (112). In this review I want to discuss the most recent study results, introducing, however, research results published in Dutch, Polish, Russian and Finnish, which may not be so well-known because of the general lack of knowledge of these languages. In one of his articles, Jansen (44) widely discusses research work carried out in the Soviet Union, pointing out that changes in hearing, in particular, have been studied in complex exposure situations. Although a great deal of interest has recently been focused on studies concerning the effects of the combinations of the different properties of noise (16, 36, 41, 111), I have omitted an introduction of these research results from this article. I have done so only because of shortage of space.

Summing up, we may say that our task today is to determine the most important combinations of environmental factors and their possible effects on the human organism. In the present-day structured environments the different factors constitute a multidimensioned entity from which no partial factor can unreservedly be omitted or detached to scrutiny on its own. From the point of view of practical labour protection, it is justifiable to take into account factors related to individual and his environment. This is already being done with respect to noise.

Pursuance of any research is subject to economic considerations and social relevancy. If we state that a reduction in noise level of one decibel would improve the productivity of work by one per cent, it is almost certain that the optimisation of several factors would mean a greater increase in productivity. Because of complex effects like these, more detailed estimates presuppose accurate calculations. However, there is also a need to put forward the kind of general views to which I refer below.

With the aid of the research data produced, it should be possible to evaluate both single factors and several factors together in the light of different criteria: e.g. not only hearing or equilibrium regulation, but also the functioning of the other senses and performance capacity. This, again, means that the principles of norm setting, solutions concerning planning and dimensioning, practical labour protection measures and even the use of safety protectors, must be viewed from a new angle, since the new research data is indicating how the environmental factors may affect and be reflected by the human organism. Identification of the properties of the individual factors included in the combinations, which either reinforce or cancel out each other's effects, means diversification of existing knowledge and availability of an increasing number of alternative solutions. The timing and duration of consecutive or cyclic working periods will for this reason emerge in a new light.

Ultimately, the results of research on combined effects will create a greater need than earlier for the kind of statistical-methodological development work aimed at solving problems related to the analysis and description of multidimensional phenomena, including the principles related to the establishment of environmental indices and other combined indicators (1, 42, 61, 107). The same can simply be presented by posing the question of how it will be possible in an unbiased and very economical way to predict whether the combined effects of environmental factors are additive, synergistic or substitutive. It is evident that the aptness of activities related to environmental planning and regulation is largely dependent on the answer to this question.

ACKNOWLEDGEMENTS

The Academy of Finland has financially supported my experimental studies.

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PROPOSAL FOR A SCIENTIFIC PROGRAM

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INTRODUCTION

At the third International Congress on Noise as a Public Health Problem at Freibourg in 1978 our team 3: "non-auditory physiological effects induced by noise" proposed to concentrate (some of) the research on three topics: critical groups, critical sources of noise and critical situations (Ettema 1980). In this meeting we have heard some results of these recommendations. Sensitive groups, among which human fetus; several sources of noise as traffic noise, industrial noise and more specific impulse noise, infrasound and ultrasonic noise; and several situations, in which other stressors were present, were discussed in the studies presented. In some cases it was possible to clear part of the problem by making the situation of research more sensitive. However, in other cases it was above all demonstrated how difficult research in this field can be and how interactions of a great number of intervening factors can obscure the effects of exposure to noise. As stated in the introduction the problem is very complex and has many aspects. It is therefore very difficult to bring back all the contributions to one concept.

Some developments in research and thinking about research in the last

period of five years lead to indications how to proceed, and how by concentrating some of the research on a few topics in international cooperation the aim of serving public health can be brought nearer.

CONFOUNDING FACTORS AND CONFLICTING RESULTS

The results of several studies are not always corresponding. There are many conflicting results and therefore interpretations. Reproduction of a study is not easy, because small differences in design may lead to small or even great differences in conclusions. Some examples will be given.

In our experimental studies on the effect of noise on circulatory parameters we worked close together with another Dutch institute, and did the same kind of experiments. We found some different effects of exposure to noise. For example, no influence or even a decrease of the systolic blood pressure was found in our laboratory (Mosskov et al. 1977), an increase in the other institute (Rövekamp 1983). This difference might be due to the posture of the tested persons, in the first case a sitting posture, in the other case a more recumbent posture.

The influence of exposure to aircraft noise on birth-weight of newborn was very small or could not be demonstrated significantly in a German and in a Dutch study (Rehm et al. 1978, Knipschild et al. 1981). A few years before in Japan - however - a very pronounced influence was found by Ando et al. (1973). By studying the level of exposure (not easy as each country has its own method of measuring the level of aircraft noise), we found that exposure in Japan was very much higher than in the two European situations.

In a first study Knipschild et al. (1979) did not find an influence of exposure to traffic noise on blood pressure. As Rehm (1983) stated already, it might be that the population studied (women 40-49 years) was not the most sensitive. In a following study however another explanation was

brought up. In that study a dose-effect relationship between exposure to noise and annoyance was found and also, that people living in streets with much traffic-noise had closed their windows at the front-side more often than people living in streets with less traffic noise (Meijer et al. 1982). No influence on the risk of hypertension was found (Knipschild 1983). The population studied was again not so sensitive (men and women 40-43 years of age), but also exposure to noise was not as high as would have been expected from the sound-measurements in the street. Moreover - compared with exposure to aircraft noise - the level of traffic noise - expressed both in Leq - is lower. Neus et al. (1983) also did not find a change due to traffic noise in the risk of hypertension in noisy areas. They suggests to study more extreme situations.

The influence of industrial noise on circulatory or cardiac disorders is reported in many publications. But in all this studies other factors could have contributed or even caused the found increase of cardio-circulatory disorders. In a series of 6 studies done by our laboratory only in 50% an influence of exposure to industrial noise on the risk of hypertension could be found, when taken into account the influence of age, exposure time and of other factors (Van Dijk et al. 1982, Ettema et al. 1982). From experimental studies it is known that some factors as dynamic load abolish the effect of noise, other factors as static and mental load, climate etc. increase the effect of noise (Ettema et al. 1980 a). In epidemiological studies in industry one has to reckon with the "healthy worker" effect, that might be much greater than expected. From the study by Van Dijk (1983) it seemed that the risk of hypertension in the workers above 50 years still present at the workfloor did not increase. The only conclusion can be that many workers with small impairment of health and above 50 years of age are

leaving beforehand or at least have their work changed to a less compelling place and working situation.

This all makes clear that we have to be very careful in setting up an experimental or epidemiological study and have to correct for such factors as age, years of exposure or factors in work and working situation (all these factors are often interrelated, so that correction for a given factor is very complicated). We have to keep in mind that small differences in design might lead to other results. As already stressed by Rehm (1983) especially with epidemiological studies the risk of noise can only be assessed sufficiently when a multifactorial design is used.

In industry a cross-sectional epidemiological study only among the workers present during the study will lead to underestimate the risk of exposure to noise. Therefore if possible longitudinal studies, cohort or case-control, will be necessary.

NEED OF COMPREHENSIVE MODEL

Westman and Walters (1981) state: *"We lack a comprehensive model to ensure that research on sound includes the critical variables that make it a significant source of human stress. Much of the research ... suffers from methodological inadequacies because noise is but one of a number of variables effecting complex human beings"*. I think we can agree and support their pleading ›r a comprehensive model as a basis for further studies. They outline several variables known from psycho- and neuro-physiological studies and especially stress-studies, which are important to be able to evaluate the influence of noise on human well-being.

When they state: *"More than other pollutants noise interacts with other sensory stressors, population density, life change and life circumstances ..."* and further: *"When seen in the context of all of these factors,*

however, noise often emerges as the one most accessible to preventive and remedial action" we not only agree but are inspired to go on with the study of the extra-auditory physiological effects induced by noise.

As often stated: noise is the oldest, perhaps the most important, but as such often not recognized, pollutant of our environment.

RECOMMENDATIONS MADE BY THE WHO

In their Environmental Health Criteria 12 on Noise (WHO 1980) The World Health Organization came to the following recommendations:

> Further studies should include:
>
> (a) The identification of long-term health effects due to high level industrial noise and lower level general environmental noise. The potentional contribution of noise stress to the general morbidity of the population, the ability of people to adapt to environmental noise, and the possibilities of noise-induced disease must be established not only for the working population, but also for the more vulnerable population segments, including the elderly, pregnant women, people undergoing medication, particularly with ototoxic drugs such as salicylates, quinine, and certain antibiotics, and those generally under stress. ...
>
> (b) ...
>
> (c) ...
>
> (d) Longitudinal studies of communities exposed to major changes in environmental noise to refine existing dose-response (noise-annoyance) relationships and to include the effects of adaptation and societal changes on public reaction to noise. Attention should be given to the study of the response of specially vulnerable segments of the population.
>
> The methods of study should be internationally uniform, as far as is feasible, to allow pooling of data and broader interpretation of the results.

This recommendations are in line with our discussions and considerations.

As concerns international cooperation we can learn from some other noise teams, e.g. on sleep. Supported by funds from the European Community several institutes from different countries worked close together with an uniform design and had very good results. The European Community already supports an Institute in Germany and another in the U.K. for studies on: Noise as a risk factor for cardiovascular morbidity. Such a study on a

restricted theme might be very fruitful when done by more groups in several countries under the condition that they cooperate intensively, work with an uniform design and handle the data in the same way.

RECOMMENDATIONS

As conclusion a few recommendations on priorities for (a part of) the future studies can be derived from the lectures and discussions in this meeting.

1. There is need for a comprehensive model of sound as a source of human stress to prevent methodological inadequacies in further research.
2. In setting up new studies multifactorial design and elaborate statistical methods are necessary.
3. Concentration on a few topics, especially cardiovascular morbidity, is recommended.
4. International cooperation has to be stimulated.
5. From a viewpoint of Public Health longitudinal epidemiological studies have an high priority.

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Poster Session

EPIDEMIOLOGICAL STUDY OF THE PREVALENCE OF ARTERIAL HYPERTENSION IN SUBJECTS EXPOSED TO CONTINUOUS AND IMPULSE NOISE

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INTRODUCTION

No clear association between exposure to noise and arterial hypertension has as yet been established. An increase in the prevalence of hypertension in persons engaged in noisy occupations was observed by Kavoussi, 1973, Capellini, 1974, Manninen, 1979 and Raffi, 1980, whereas Takala, 1977, Less, 1979, and Malchaire, 1980 found no variation.

This paper examines the question with particular regard to noise characteristics and intensity levels.

MATERIALS AND METHODS

The study relates to 1488 male workers in the province of Como employed by the day or on two daily shifts in jobs requiring slight or average physical effort, and not exposed to agents toxic to the cardiocirculatory system.

Histories describing previous and present occupational tasks, length of Service, civil registry data, standardised pleasure-giving habits, and exposure to noise (if any), plus noise intensity and characteristics were available for all subjects. Three groups were formed: 365 subjects exposed to continuous noise of more than 80 dB A; 436 exposed to impulse

noise of more than 90 dB A; 667 not exposed to industrial noise (Table 1). The differences between the three groups were not statistically significant.

	N°	ETA' MEDIA e deviazione standard	FUMO		TURNI	
			SI	NO	SI	NO
RUMORE CONTINUO	385	37,6 ± 11,4	235	150	143	242
CONTROLLI	667	38,2 ± 12,3	396	271	220	447
RUMORE IMPULSIVO	436	37,8 ± 11,2	259	177	145	291
TOT.	1488	37,97	890	598	508	980

Table 1 - Main characteristics of subjects exposed and not exposed to noise.

The indications given by Coles & Rice (1970) were used to classify the findings obtained with a Bruel-Kjaer Model 2209 phonometer. Blood pressure was measured according to WHO criteria in the course of comprehensive occupational medicine and hygiene investigations. Hypertension was diagnosed when the systolic pressure was 160 and/or the diastolic pressure was 95 mm Hg.

RESULTS

The data for the three groups are shown in Table 2. They are also related to age. There is a significant difference in the proportion of hypertensives in subjects exposed to impulse noise, as opposed to those

not exposed to industrial noise (χ^2 = 17.65, one degree of freedom). This was not the case in the continuous noise group. The differences between the three age classes considered were significant in all three groups (χ^2 = 27.91, 8.95 and 7.49 with 2 degrees of freedom for con tinuous noise, impulse noise, and no noise respectively). The literature is concordant on this point.

Rapporto fra Tassi	χ^2	I.A. %	N°		CLASSI DI ETA'	I.A. %
0,89	0,45	48	385	RUMORE CONTINUO	15 - 30	5
					31 - 40	5
					> 40	38
		93	667	NON ESPOSTI	15 - 30	15
1,71	17,65				31 - 40	27
					> 40	51
		104	436	RUMORE IMPULSIVO	15 - 30	17
					31 - 40	31
					> 40	56

Table 2 - Distribution of hypertension in the three groups considered and in function of age.

Table 3 illustrates the prevalence of hypertension in subjects exposed to noise in function of their length of exposure and the ambient levels concerned. In terms of duration of exposure, there was a significant difference between the classes in workers exposed to continuous noise (χ^2 = 11.97), whereas this was not the case with impulse noise. The opposite was true with regard to prevalence and noise level. There was no increase in function of noise level in subjects exposed to continuous noise, whereas there was a distinct increase for impulse noise. The trend was significant (χ^2 = 35.90-33.21 = 2.69).

I.A.	NORMALI	ANNI ESPOSIZ	RUMORE	ESPOSIZ dBA	NORMALI	I.A.
11	129	1 - 5	CONTINUO	< 90	161	21
17	141	6 - 15				
20	67	> 15		> 90	185	27
				dBA		
29	103	1 - 5	IMPULSIVO	< 100	147	21
41	137	6 - 15		101-110	92	21
34	92	> 15		> 110	93	62

Table 3 - Distribution of hypertension in function of length of exposure to continuous and impulse noise and its levels.

CONCLUSIONS

Our findings indicate that hypertension is distinctly more prevalent in persons exposed to impulse as opposed to continuous noise. It is thus caused not so much by noise in general as by a particular type of noise. Subjects exposed to continuous noise, in fact, had no greater prevalence of hypertension than those not exposed to industrial noise at all (12.46% as opposed to 13.94%). An association between exposure to continuous noise and hypertension can possibly be spelt out of the significant increase in hypertension in function of duration of exposure. This finding, however, is an isolated datum. In addition, seniority at work is closely associated with age, which is known to influence pressure levels. One is therefore dealing not with a dose-response effect, but a consequence of aging. The picture is very different in the case of impulse noise. Hypertension was observed in 23.85% of this group, as opposed to 13.94 % in the controls. As already stated, this difference is significant.

The relation between prevalence and sound level is of particular interest. Prevalence increased in function of level at an almost constant rate, as shown by the chi-square result for the trend. The absence of significant differences in function of years of exposure in spite of sligth increases suggests that hypertension begins early, and that both

the impulsive nature of noise and its level are primarily responsible. The reversibility of hypertension in subjects exposed to impulse noise is an open question. The impression gaines from repeated examination of some subjects during long periods of repose was that a stable situation exists. A better answer may be forthcoming from further studies of the long-term effects of hypertension in a cohort of persons exposed to impulse noise.

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Noisé, exposure, labour conditions and Anxiety.
Test data for the State-Trait Anxiety Inventory (STAI)

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Introduction

"Personality States are defined as transversal moments of short length during the life of a person (Spielberger 1966-72). Personality traits are generally defined as different individual tendencies to react or to behave in a given way.

State anxiety has been defined to be a transitory state characterized by feelings of strain and anxiety and by an increase in the activity of the Autonomous Nervous System (ANS).

On the contrary trait anxiety is the possibility, which may be different according to subject that a single person can experiment anxiety states as an answer to situations of strain determined by the social environment.

The subjects persons that appear to have a high trait anxiety are more prepared to experience their relationship with other people as a menace and to answer back with a significant and intense state anxiety" (Pancheri P., Bernabei A. et all 1976).

Among non-auditory effects of environmentail noise, psychological effects are those of more difficult approach, because they can be measured only indirectly (trough the study of performance) or subjectively (through, questionnaires).

According to Jansen (1959) the subjects that are exposed to a higher level of noise have a higher emotional strain both at home and at work (Broadent 1961, on the contrary, says that noise exposure causes measurable changes. in psychomotory performances mainly with reference to the personality of the subject under exam: the subjects that have previously been diagnosed as anxious show greater alterations of their performances as a consequence of noise exposure.

The aim of this report is that of examinating the existence of a relationship between noise exposure and anxiety tract.

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Matter and Methods

During a screening carried on by the Preventive Medicine Mobile Unit of the FS (Italian State Railways), 381 voluntary persons (375 males and 6 females) aged from 20 to 60 years have been examined.

They have been subjected to an audiometric test in silent cabin with standard auditive stimulations for intensity and tone; afterwards they have been evaluated according to the methods proposed by Merluzzi (1976) which permits the subdivision in eight classes (class Ø = no damage; classes from 1 to 5 = noise damage of increasing entity; class 6 = transmissive-perceptive bradyacusic damage; class 7 = transmissive bradyacusia (not caused by noise). Twenty-six out of the 381 subject were not tested because of the presence of earwax; the resulting 355 (349 males and 6 females) have been subdivided into three groups according to their task: workshop workers (250); staff employed in train driving, engine drivers (111), and office clerks.

For the quantity determination of the anxiety level we have used the italian edition of the state and trait anxiety self-evaluetion inventory STAI) by Spielberger (1981), that was applied individually by means of a micro-computer VIC 20. Commodore which, duly programmed gave us the evaluetion in real time.

For each subject we have reckoned points referring to trait anxiety and points referring to state anxiety; moreover we have assumed that tne age ðf the subjects is the index of their years of work and consequently of their noise exposure, because the age of their employment at the FS service first was homogeneans.

As the number of the female subjects was small (they have been all included in the class Ø) , we have decided to deal with our data without any sex discriminations.

Pict.1

CL	WO	En.Dr.	O.Cl.	Tot.	<35	36-45	>46	Tot.
Ø	154	65	9	228	103	84	41	228
1-5	67	43	5	115	15	25	75	115
6-7	9	3	-	12	2	3	7	12
Tot.	230	111	14	355	120	112	123	355

Pict.2

	CL	N°	X (Trait Anxiety)	SD (Trait Anxiety)	X (State Anxiety)	SD (State Anxiety)
Wo	Ø	154	36,61	6,4	37,65	7,63
	1-5	67	38,18	8,2	37,62	8,08
	6-7	9	39,9	10,6	36,77	4,77
En. Dr.	Ø	65	34,85	6,96	36,96	7,32
	1-5	43	34,35	1,6	37,04	4,91
	6-7	3	35,67	4,1	38	1,412

./.

	CL	N°	Trait Anxiety		State Anxiety	
			$\bar{x}$	SD	$\bar{x}$	SD
Office Clerks	Ø	9	36,66	8,84	36,88	9,87
	1-5	5	41,4	7,17	39,2	7,47
	6-7	-	-	-	-	-
	Ø	103	34,68	6,4	36,36	7,23
Age < 35	1-5	15	38,26	9,46	35,6	7,63
	6-7	2	47	9	43	0
" 36-45	Ø	84	37,27	7,92	38,33	8,53
	1-5	25	35,6	8,15	38	8,09
	6-7	3	47	9,27	36	4,55
	Ø	41	36,9	8,59	38,02	7,39
" > 46	1-5	75	37,04	7,11	37,61	6,71
	6-7	7	32,85	5,16	35,86	2,99
Total Sample		355	36,41	7,71	37,39	8,25

Pict.3

	Trait Anxiety		State Anxiety	
	t	p	t	p
FS.'83/Pancheri '76	4,3	< 0,001	3,29	< 0,001
(1-5) (Ø)	0,95	n.s.	0,04	n.s.
(1-5) 35 (1-5) 36	0,61	"	0,99	"
Ø 35 Ø 36	2,55	< 0,002	1,83	"
Workers/Eng.Drivers	5,14	< 0,001	0,73	"
" (Ø)/ " (Ø)	1,74	n.s.	0,63	"
" (1-5)" (1-5)	3,71	< 0,001	0,46	"
Workers (Ø) (1-5)	1,38	n.s.	0,03	"
Engine Drivers (Ø) (1-5)	0,56	"	0,07	"

Results

The first analysis of the distribution of the sample subdivided according to the qualification and to the levels of noise damage (table 1)shows an even distribution of the auditory damage of the two principal component parts (engine drivers and workers),thus confirming the initial hypothesis of an analogous exposition (X^2 = 3,28,n.s.). Subdividing in bands of age the whole sample we obtain a distribution as exposed in the right side of table 1; from this it is possible to notice a significant different trend in all bands,that is a decrease in state of auditory standard (class Ø)in parallel to the advancing age and the increase noise bradyacusie (class 1-5) . We have therefore anlysed the different incidence of the two components of anxiety, of which table n.2 describes the arithmetic means and the standard deviation for each group and undergroup,divided according to the working qualifications and the bands age. Table n.3 shows the values of the comparison between the various groups obtained using student's statistic test. In

table n.3 we have thus recapitulated all the figures obtained;on the first line we have written the figures referring to the whole sample of subjects aged under 35,comparing it with the analogous italian sample referring to university students that is shown in Pancheri ('76).Both the parameters have shown to be inferior to the mean,being in concordance with the datum that is present in literature about the influence of the cultural level in this kind of tests.(Simon A,Thomas A,'83). No meaningful difference can be noticed when we consider noise exposed bradyacusic subjects as a whole (class 1-5 of Merluzzi) in comparison with the normal subjects (class Ø). While the analysis of the variance to a way has shown a difference in the three classes af age (≤35, 36 + 45 ,≥46), an appropriate study with the 't' of student hasn't shown any significant differences in the bradyacusic 35,while,for the normal subjects, the difference of age has given significant figures, showing an increase in the average levels of trait anxiety as the age the subjects gets on. As regards the comparison with groups of different qualification we have noticed that workers,on the whole , have average levels of trait anxiety higher than engine drivers. If we then analise the single groups subdividing them according to their auditory state, we notice that while there is no difference among the normal subjects (class Ø), there, appears to be a difference in the bradyacusic people of the two groups, being the workers <u>in the trait anxiety significantly</u> more anxious than the workers. Within the groups the different qualifications haven shown meaningful differences when we consider the auditory damage.

<u>Conclusions</u> - In a group of subjects with a significant and progressing noise exposure and with ensuing bradyacusia the average, levels of state and trait anxiety don't seen to be <u>correlated</u> to it . Nevertheless it is possible to point out some indications about a greater association the qualification of the subjects (workers) the auditory damage ,and the high level of trait anxiety , which suggest the need for further search.

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NON-AUDITORY SYNERGISTIC EFFECTS INDUCED BY NOISE AND INHALED CHLORORGANIC SOLVENT VAPOURS

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INTRODUCTION

Noise pollution has been considered to be the highest risk for occupational health. Noise induced hearing loss is the mostly occurring professional disease and noise protection precautions are based on this indicator. But nonauditory physiological effects induced by noise so far have not been accepted as a harm to the same extent. One reason for this may be that these effects are not highly specific with respect to noise as the inductor, they are mediated by hormones and may be caused also by other physical, psychological or social stress situations.

As the non-auditory effects are involved with a series of biochemical reactions, an interference with other biochemical reactions resulting from other pollutions, chemical ones f.i., may occur. From industrial hygiene studies it is known that those workers who are exposed to high noise levels are also exposed to a higher mean concentration of atmospheric chemical pollutions than others workers. So one should look for synergistic effects.

To evaluate synergistic effects, epidemiologic studies we estimate are not well suited because unrealistic population

numbers would have to be investigated in order to discriminate between the effects of different pollutants and other kinds of stress. So we constructed laboratory experiments with rats where the synergistic effect is evaluated besides both monoergistic effects and a control population. The both effectors are stochastically applied noise-frequence-adapted to the rat ear response - and the widely used organic solvent 1,1,1-trichloroethane (TCE). In this study the effect on the liver microsomal monooxygenase system is investigated. This enzyme system is the main metabolizing site for a wide range of xenobiotica as drugs and carzinogens.

METHODS

We have built a simulation chamber with an inner volume of 18 m^3 (Figure 1). The walls are sound absorbing (55 dBA) and

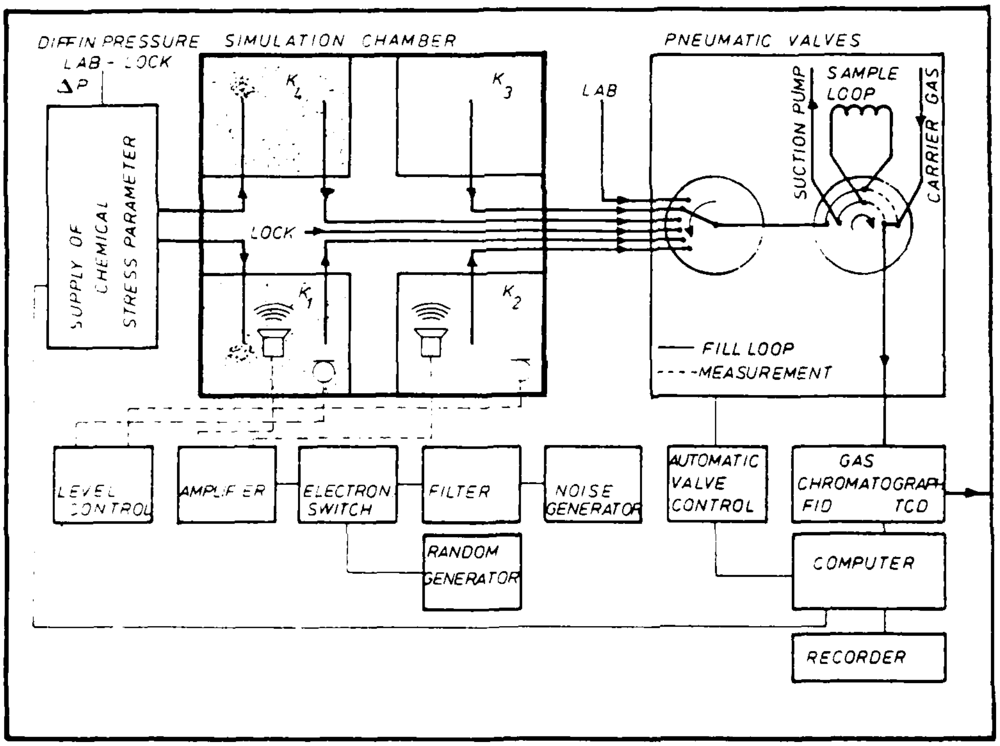

Figure 1:

Simulation chamber for the evaluation of synergistic noise and chemical effects.

are thermoregulated at the same temperature as the volume of the chamber, because volatile chemicals should not condensate at the walls. The chamber volume is passed by a stream of air, which can be increased up to 1500 m^3/h. Temperature and humidity can be varied within physiological ranges. The incoming air passes one mechanic and one sterile filter, the waste air passes a charcoal filter.

Within the chamber four boxes are installed each with a volume of 2 m^3. The boxes are isolated against each other and against the rest of the chamber which serves as a lock chamber. On safety reasons the whole chamber is under negative pressure of about 6 mbar. In case of emergency a big exhaustor on line with an emergency power plant cleans the whole chamber within a few minutes.

The boxes K_1 and K_2 are stochastically applied with an equivalent white noise level of 90 dB related to the ultrasound hearing frequency of the rat ear. The boxes K_1 and K_3 are equipped with evaporators which sustain an atmosphere with 2000 ppm (10 times the TLV-value) partial pressure of 1,1,1-trichloroethane or chlorothene (i.e. technical TCE). The effectors were applied 12 hours per day during 84 days. Then the rats were killed, body, liver and kidney were weighed, liver microsomes were prepared according to standard methods and their deethylation activity for 7-ethoxycoumarin was measured, which is an usual test for the enzymatic activity of liver microsomes.

RESULTS AND DISCUSSION

The first results from three studies are given in tables 1-3. In all three studies the rats in groups 2 and 4 (columns 2 and 4) have been exposed to noise as described under Methods. The rats in groups 3 and 4 (columns 3 and 4) were exposed to 1,1,1-trichloroethane in study 1 and to chlorothene^R (i.e. technical 1,1,1-trichloroethane containing about 10 per cent additives) in studies 2 and 3 as described under Methods. Group 1 (column 1) always is the control group. Each cross is the result from

one rat. A Kruskal-Wallis-Rank test has been performed. The test-statistic H-value and the rank sums are given at the bottom of the tables.

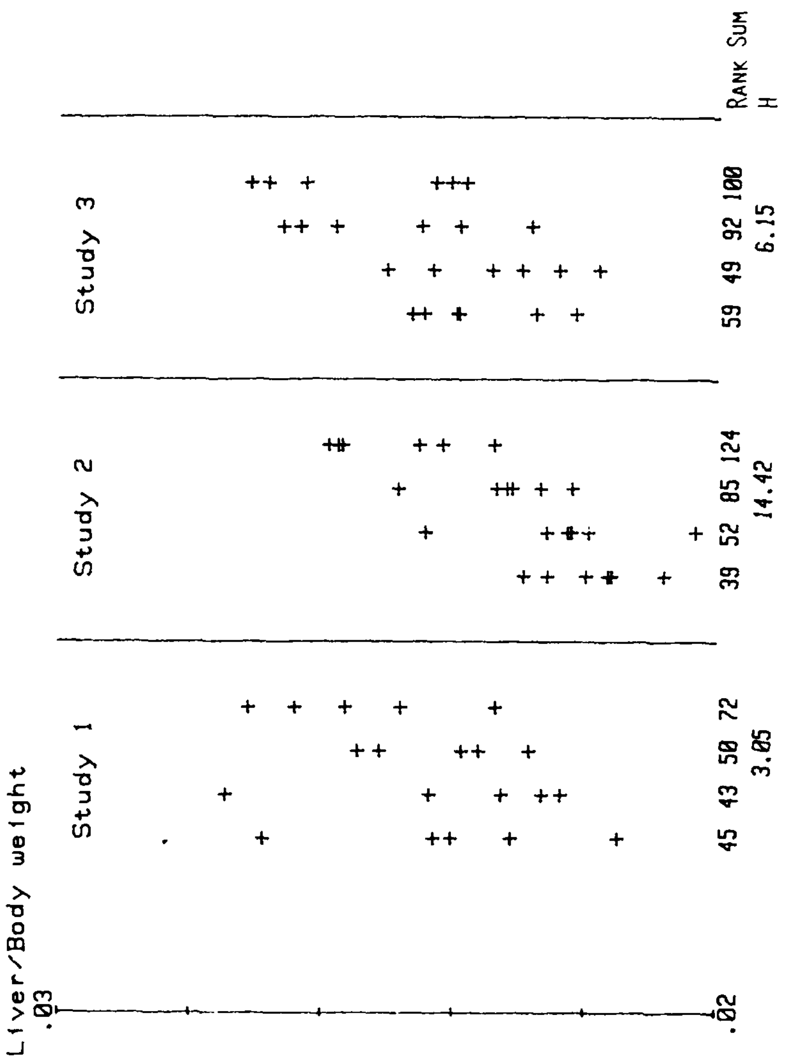

TABLE 1

Table 1 shows the relation of liver weight to body weight. Noise pollution always increases this relation in the presence of the chemical. The result is highly significant in study 2. The increase cannot be stated between noise groups and control groups.

No differences with respect to noise have been evaluated for the relation kidney weight to body weight (not shown here).

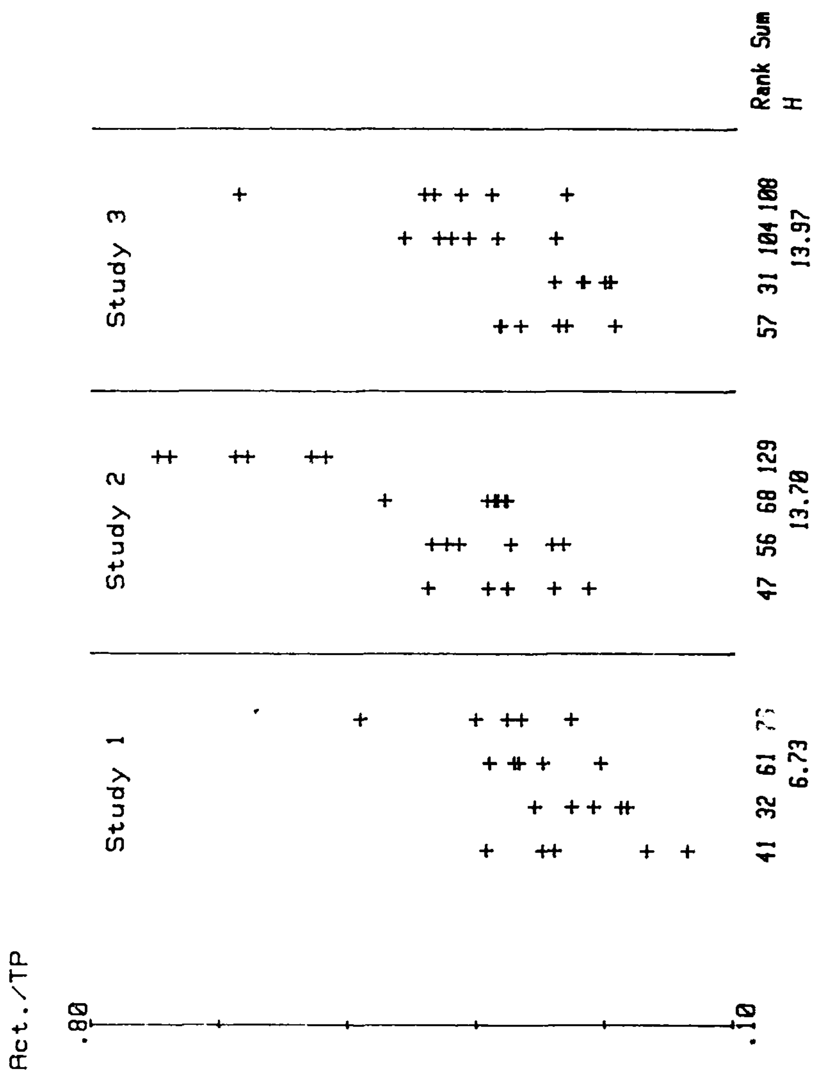

TABLE 2

Table 2 shows the enzymatic activity of the liver microsomal monooxygenase system. The results correspond to those from table 1: In the presence of the chemicals, noise induces a higher enzymatic activity, which is highly significant again in study 2. No induction is induced by noise alone.

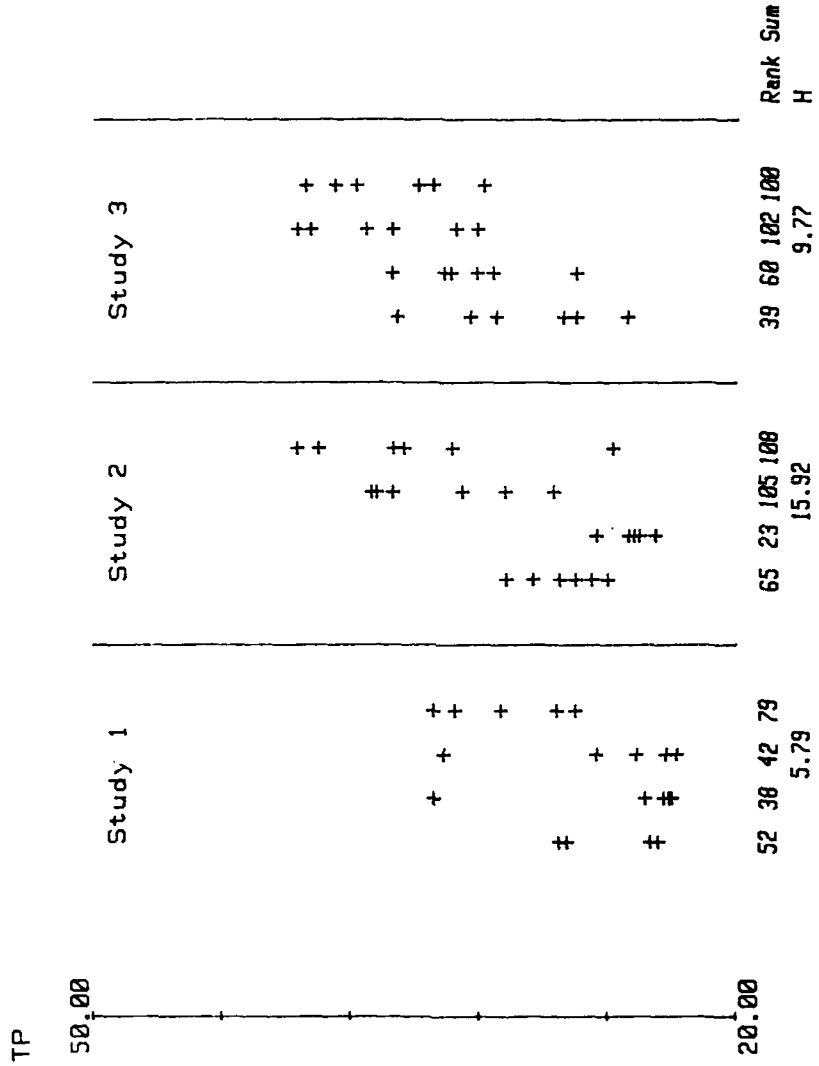

TABLE 3

Table 3 shows the total protein content of the rat liver microsomes. Noise pollution increases the protein content in the presence of chemical pure TCE (study 1) but does not effect further the higher levels of protein content in the presence of the technical TCE which itself produces a higher protein content with respect to controls (studies 2 and 3). Here also the rats exposed to noise alone got no liver microsomal protein increase compared to control rats.

Subjective and physiological response to intermittent noise.

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Noise exposure

The test persons were divided in three groups. Each group of 10 persons was assigned a special exposure program with different mean inter-trial intervals

Group I	: ITI	=	45	seconds
Group II	: ITI	=	3	minutes
Group III	: ITI	=	10	minutes

The noise bursts had a duration of 4 seconds with a maximum level of 80 dBA. The background level was 40 dBA. Each test sequence lasted 90 minutes. The total noise exposure for each group corresponds to an equivalent level of:

Group I	: L_{Aeq}	=	64 dBA
Group II	: L_{Aeq}	=	58 dBA
Group III	: L_{Aeq}	=	53 dBA

Test situation

Each test person was individually exposed to the noise stimuli. The person was comfortably seated and instructed that this was an experiment concerning physiological habituation to noise. The test person was not assigned any particular intellectual task, but were allowed to read any "non-professional" material of their own choise. The physiological parameters were directly recorded by a computer throughout the experiment. Heart rate was measured by electrodes affixed to the chest and finger pulse amplitude and galvanic skin conductance was measured by electrodes on the fingers of their "best hand" (hand used for writing).

At the end of the session the test subject was given a questionnaire and interviewed about their subjectiv attitudes towards the nosie stimuli.

Results

The test results are shown in figure 1-3. Skin conductance response and pulse volume response is the average response for all 10 persons within each group for every 18 minutes. The heart rate response is the average response for a 10 seconds periode after the stimulus onset for all stimuli within a test session.

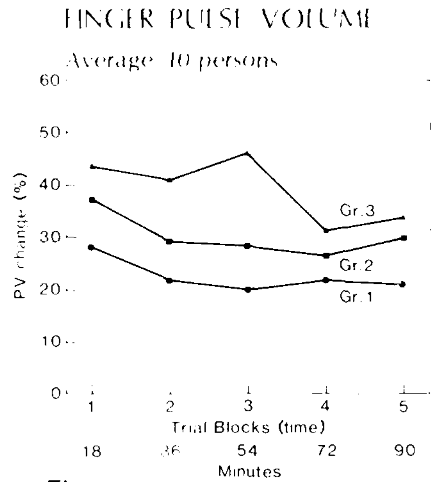

Figure 1.

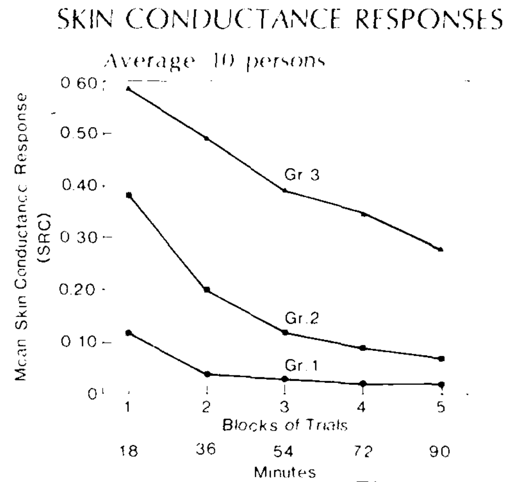

Figure 2.

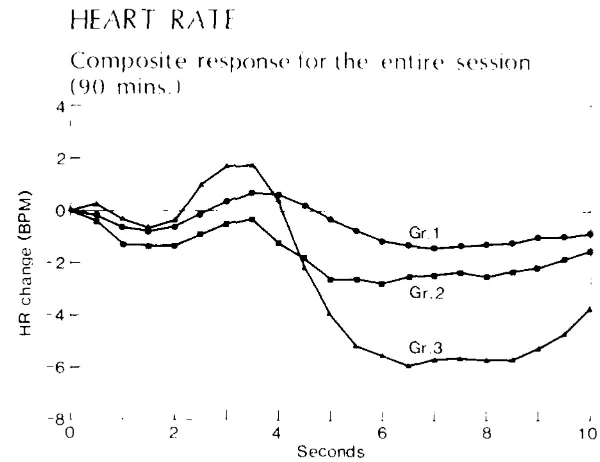

Figure 3.

Discussion

This pilot test shows that for all 3 physiological parameters the largest response is observed in group number 3 which received the smallest noise dose. The most negative subjective response is also observed in that same group.

These facts prove that there is no simple correlation between the energy equivalent continous A-weighted sound level, L_{Aeq}, and the assessment of noise annoyance for this type of exposure.

For interrupted noise, like fly-overs or pass-bys, the inter-stimulus-interval (time between noise events) is an important factor that must be taken into account when assessing the total noise impact.

MULTIPLE SKIN CONDUCTANCE RESPONSES TO AIRCRAFT NOISE WITH VARYING RECRUITMENT TIMES

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INTRODUCTION

Recruitment time, defined as the increase in noise level per unit time, e.g. when discrete noise events from traffic or aircraft rise above the background level and reach their peaks, has not been directly addressed in human noise research. Standard noise indices, such as the mean energy level (Leq) and what noise levels are exceeded certain percentages of the measurement time (Lpn, where p is level and n is percentage), do not explicitly consider degree of fluctuation in the levels, and its distribution in time. Nor do noise and number indices or indices based on peak levels by themselves differentiate between recruitment times.

When changes in recruitment time increase the Leq-level or the Lpn of a noise event, human reactions will also increase. However, when changes in recruitment time are not accompanied by changes in Leq or Lpn, psychological and psychophysiological theorizing around orienting-defensive reactions, as originated by Sokolov (1963) would be of relevance (see Kimmel, van Olst & Orlebeke, 1979 for further references). In that context a fast change in a stimulus, e.g., a rapid increase in noise level, would cause a more pronoun-

ced orienting reaction than a slow one. Given that the noise level reached is sufficiently high, this would also cause a defensive reaction. Orienting reactions habituate with trials, whereas defensive reactions do not. Thus we have here a conceptual framework for predicting some effects of repeated noise with varying recruitment times on human reactions. The present study was designed to investigate such predictions.

A second objective of the present study was to find out whether a standard psychophysiological measure such as the skin conductance response (SCR), which has been widely employed in orienting-defensive research (see Kimmel et al., 1979), could be useful also in noise research.

METHOD

Thirty-two women and as many men in the age interval from 18 to 72 took part in the experiment. Noise stimuli and their variations are depicted in Figure 1. The eight different stimuli were presented two times each in randomized blocks, and the first and last stimuli were the reference noise. Noise stimuli were presented over loudspeakers against a broad band 50 dBA noise. SCRs were recorded from fingers on the non-dominant hand, and scored in six time intervals as shown in Figure 1.

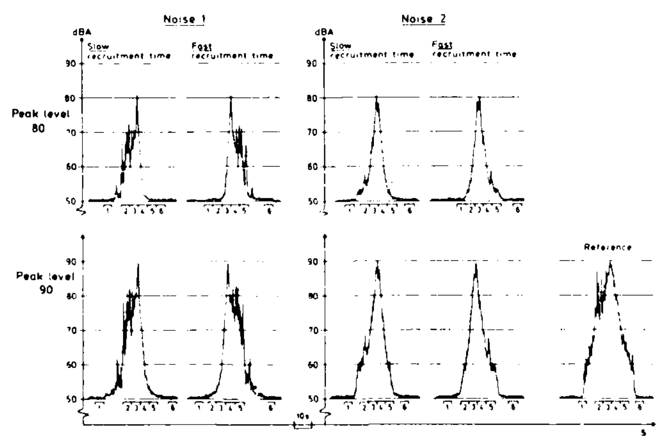

Figure 1. Noise stimuli and scoring intervals.

The subjects were instructed to rate the background noise as 25, and the first aircraft noise to be presented (the reference) as 100 on a subjective annoyance scale. The inter-trial interval was 160-240 sec, and noise ratings

were taken after each trial.

SCRs in the six scoring intervals and annoyance ratings were transformed to log fractions of that subject's maximum SCR or rating. The whole experiment formed a dependent measure x noise pattern x peak level x sex factorial design with sex as the only between-subject variation, and was analyzed as such in a multivariate analysis of variance (MANOVA).

RESULTS

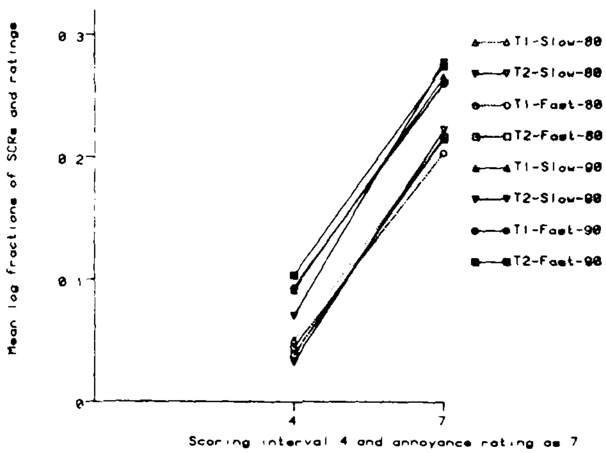

Figure 2. Means of SCR in interval 4 and annoyance ratings.

The MANOVAs were performed in two steps. First there was an inspection of significant effects and orderliness of data over the six scoring intervals and the annoyance ratings as dependent measures. From that inspection it was concluded that interval 4 SCRs and the annoyance ratings could usefully be analysed further. The results from that analysis are complex in therms of higher order interactions. However, all significant effects can be subsumed under four interactions: peak level x recruitment time, $\underline{F}(1,62) = 7.09, \underline{p} < .010$, noise pattern x recruitment time x dependent measure, $\underline{F}(1,62) = 8.90, \underline{p} < .004$, recruitment time x trial x dependent measure, $\underline{F}(1,62) = 7.19, \underline{p} < .009$, and sex x peak level x noise pattern x trials x dependent measure $\underline{F}(1,62) = 6.27, \underline{p} < .015$.

In terms of the predicted effects of recruitment time, peak level and

trials, follow-up Tukey tests indicated that interval 4 SCRs increased from slow to fast recruitment time for Noise 1 (Tukey LSD(62) = .009, observed = .022), which was not paralleled by Noise 2. Also, for the same interval 4 SCR there is an increase from trial 1 to trial 2 for slow (Tukey LSD(62) = .009, observed = .020), but not for fast recruitment times. Thus the predictions of the effects of recruitment time were not confirmed. Peak levels had a highly significant main effect, $\underline{F}(1,62) = 222.70, \underline{p} < .001$ and follow-up tests indicated that peak level 90 resulted in more responding than level 80 across all orthogonal pairwise contrasts (Tukey LSD(62) = .028, all observed > .028. For annoyance ratings there was a significant increase from trial 1 to trial 2 (Tukey LSD (62)=.011, all observed > .011), but not so for interval 4 SCRs.

CONCLUSIONS

Recruitment time does not seem to have a reliable effect upon human reactions when Leq or Lpn are kept constant. Repetition of noise stimuli seem to increase annoyance ratings, but not SCRs. SCRs are in some ways a useful dependent measure in noise research.

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TRAFFIC NOISE AND HYPERTENSION. THE BONN TRAFFIC NOISE STUDY.

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In animals noise was repeatedly found to induce hypertension (1-5). Similarly, in man the incidence of hypertension was often found to be higher in noisy factories (6-10).
Our team has been working on the influence of environmental noise (traffic noise and aircraft noise) on blood pressure. These investigations were based upon the idea that essential hypertension results on two necessary conditions, namely stress and genetic risk (11). In this respect, noise is understood to be one possible stressor which could elicit the pathogenetic development.
As a first approach, we contributed the medical part the Interdisciplinary Munich Aircraft Noise Study (12). As regards blood pressure, a definite relationship between noise exposure and blood pressure could not be verified. But this was because the subjects being least exposed to aircraft noise deviated from the trend of increasing blood pressure with increasing sound level. This result applied to both sexes. However, due to the interdisciplinary analysis an influence of the subjective noise reaction on diastolic blood pressure was verified (13). In the Amsterdam Aircraft Noise Study Knipschild (14) three years later described a definite relation between the percentage of hypertensive subjects and sound level.

In the years 1978-1980 we reinvestigated the problem in Bonn, concentrating on road traffic noise which can be regarded to be the most dominant environmental stressor (15). Subjects were screened from a complete list of the inhabitants of two residential areas consisting of streets with either extreme high traffic volumes resulting in an estimated sound level of at least 66 dB (A) or a control area (16). The control area has been chosen to be in close neighborhood to the noisy area with the only condition that there was no essential sound propagation from the noisy area and only small traffic. By this the estimated noise exposure was less than 51 dB (A) in this area. In both residential areas about 500 subjects were interviewed. Age and sex were equally distributed in both areas. The interviews were conducted by means of a standardized questionnaire which contained questions about medical history, especially on treatment of hypertension. Furthermore, the subjects were asked questions about noise exposure, noise attitudes (for example noise sensitivity) and tolerability of noise at home. These items were based upon the questionnaire used in the interdisciplinary study in Munich (17).
It was found that the incidence of treated hypertension was higher in the noisy area than in the control area (22.8 % vs. 14.6 %; $p=0.002$). Furthermore the longer young (20-40 years) male and female subjects lived in the noisy area, the higher was the incidence of treated hypertension ($p < 0.05$ for both sexes); this was not found for the control area. While the first result established an association between traffic noise and hypertension the latter one suggests that there may be a causal relationship.
In part of the interviewed subjects (N=165) selected at random, thorough clinical and experimental investigations were carried out. These investigations included experimental traffic noise exposure (N=56 male subjects) and other emotional and physical stress testings. The experimental traffic noise had a duration of 30 minutes at 72 dB (A). (18).

In keeping with the results of others (19) subjects with a family history of hypertension exhibited enhanced vascular reactions to noise exposure. This result supports the hypothesis that traffic noise might be a risk factor for hypertension especially in subjects with a genetic risk of hypertension. Within the 30 minutes of noise exposure there was no adaptation of the diastolic blood pressure response; furthermore, there were no differences in the reactions to noise between the residents of both areas. Thus, the vascular reactions to noise exhibit a remarkable constancy and no habituation which supports the hypothesis of a chronic influence of noise on blood pressure.

However, at present there is no prospective study aiming at the role of environmental noise for essential hypertension. As a first step follow-up data were gathered in small samples (N=28 and N=36) of normotensive paticipants of the traffic noise study who did not move, 16 and 27 months after the original investigation (20). In both investigations, the residents of the noisy area exhibited greater increases of diastolic blood pressure (5.1 mm Hg and 10.7 mm Hg; p=0.035 and p=0.006) as compared to the control group. This effect was about the same in both sexes. Therefore there is increasing evidence for an pathogenetic influence of environmental noise on blood pressure.

Further investigations were addressed to the question of the role of subjective reactions to noise. In an experimental study (21) we found no correlation between the subjective annoyance reactions to experimental noise and the reactions of blood pressure; neither was there a relation between noise attitudes or the tolerability of the traffic noise experienced at home and the blood pressure response. This study suggests that - at least under experimental conditions- the reaction of blood pressure is indep ndent from these psychological factors. In order to further clarify the possible influence of these psychological variables as a moderator of the physiological response, we reanal ed

the data of the epidemiological study (22). Restricting on the inhabitants of the noisy area, no relation between the psychological variables and incidence of treatment of hypertension could be established. However, within the control area those who rated the noise exposure as not tolerable (about 50 % of these subjects) had a higher incidence of treated hypertension (p=0.007). A similar result was found analyzing the follow-up data. From this we concluded that it may be possible to cope with small stressors but that there is no possibility to "escape" the influence of extreme traffic noise exposure by psychological means.
Summarizing, the studies cited above give evidence that environmental noise is a risk factor for essential hypertension. A final remark should be made. The onset of essential hypertension usually is characterised by an increase of cardiac output (23, 24). But the effect of noise seems to envolve primarily vascular reactions, resulting in elevated peripheral resistance and diastolic blood pressure. The specifity of the noise effect on blood pressure is further underlined by the fact that it applies to both sexes while normally there is a protective mechanism in women (25, 26). In future research this specifity should be further clarified.

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AD-A142 412 NOISE AS A PUBLIC HEALTH PROBLEM: PROCEEDINGS OF THE INTERNATIONAL CONGRE..(U) TURIN UNIV (ITALY) DEPT OF AUDIOLOGY G ROSSI NOV 83 EOARD-TR-84-08-VOL-1 8/8

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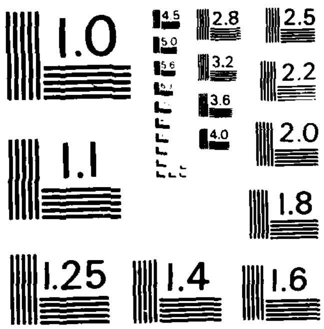

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NON-AUDITORY EFFECTS OF LOW FREQUENCY NOISE

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INTRODUCTION

The non-auditory effects of noise in mammals are mediated by the sympathetic nervous system through catecholamine secretion and by hypothalamo-pituitary stimulation of adrenocortical hormone release. Animal studies suggest an acute elevation in the plasma level of these substances during loud noise, and the development of hypertension under chronic exposure. Generalizations from the animal to the human situation are not straightforward. The meaning cognitively assigned to a noise can significantly modify the response of humans. While a noisy environment may contribute to coronary vascular disease, hypertension and gastrointestinal disorders, the data for humans is contradictory and no general agreement exists.

MATERIALS AND METHODS

Thirty-five males (ages 18-22) were selected as follows: (1) hearing threshold levels within 10 dB of ANSI-S3.6 from 125 Hz to 4.0 kHz, (2) good health, and (3) reliability of audiometric measurements. A group of 18 were exposed to 84 dBA of octave band noise centered at 63, 125 or 250 Hz for 24 hours. Due to prolonged temporary threshold shifts (TTS), exposure of a second group of 17 at 90 dBA was limited to 8 hours. Four subjects taken from this 90 dBA group were confined for 24 hours without noise, and served as controls.

The subject's oral intake was regulated for 12 hours prior to noise exposure and a standardized meal was served in the 4th and 10th hours of confinement. A high fluid intake was maintained. Two subjects were observed per session, in a

furnished apartment with a constant sound field ($\pm$ 1 dB). The subjects usually slept or read.

The effects of noise on the sympathetic nervous system were inferred from measurements of heart rate (HR) and blood pressure (BP), and from the urinary excretion of epinephrine(E) and norepinephrine(NE). HR and BP were recorded by an automated blood pressure cuff system. Subjects voided 1 hour prior to exposure, and then urine samples were collected at 0,1 and 2 hours. The urinary output of each subject in the remaining 6 hours (90 dBA) or 22 hours (84 dBA) was pooled and reported as a mean excretory rate. These were assayed for E and NE by a modification of the fluorometric technique of Crout. Plasma cortisol (C) was determined by radioimmunoassay from venipuncture samples obtained just prior to noise exposure (9 a.m.) and then 1 and 24 hours later.

RESULTS

The auditory effects differed in certain aspects between 63, 125 and 250 Hz noise, but no significant dissimilarites were observed in the physiologic parameters and the data herein represents an averaging across the 3 frequencies.

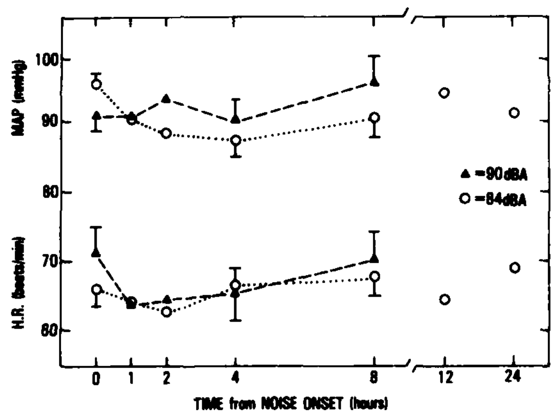

Fig. 1 - MAP and mean HR of 90-dBA and 84-dBA groups during 8 or 24 hours in noise, standard errors indicated at 0, 4 and 8 hours.

The mean HR and mean arterial pressure (MAP) of the 84 and 90 dBA groups are shown (Fig. 1). Both the systolic and diasystolic parameters increased in the 90 dBA subjects, with a 5 mm Hg rise in MAP between 0 and 8 hours. Their mean HR fell 7 beats per minute between the 0 and first hour measurements, and consistently rose thereafter towards the 0 hour level. In

contrast, the 84 dBA group's MAP decreased 5 mm of Hg during the first hour, and thereafter varied from 88 to 94 mm of Hg. Their mean HR ranged from a high of 68 (meal) to a low of 58 (sleep), with no clear trend. The control group (data not shown) demonstrated little change in either HR ($\pm$ 5 BPM) or MAP ($\pm$ 2 mm Hg).

The urinary excretion of E and NE for the 1st, 2nd and mean of the remaining 6 hours (90 dBA) or 22 hours (84 dBA) in noise are shown in Table 1, as normalized to the excretory rate of the pre-exposure hour. The lower mean E excretion for the final 22 hours of the 84 dBA subjects may reflect the depressed excretion rate in their usual 9 hours of sleep. The 90 dBA subjects' final rate does not contain any sleep-produced bias, and demonstrated little change. NE excretion in the 84 dBA group increased slightly over the first 2 hours to 16% above pre-exposure, but the mean of the remaining 22 hours differed from the initial level by only 2%. In contrast, NE decreased in the 90 dBA subjects during the first 2 hours to 22% below pre-exposure, and then stabilized for the remaining 6 hours. The reason(s) for the contrasting 0 to 2 hour patterns between the groups is not known. None of the trends noted in E and NE were statistically significant.

Table I

		HOURS IN NOISE			
		0 E & NE	1 E - NE	2 E - NE	Remainder E - NE
Noise Level	84 dBA	1.00	.85 - 1.05	.97 - 1.16	.62 - .98
	90 dBA	1.00	.69 - .82	.98 - .78	1.06 - .82

Plasma C was measured just prior to noise exposure (9 a.m.), and then at 1 and 24 hours of confinement. Nine of the 90 dBA subjects were restricted to the cots for a "quiet hour" prior to the onset of noise, and their mean C decreased 6.75 ug/dl in that hour. During the first hour of noise exposure, the downward C

trend was reversed, with 3 ug/dl mean increase in both the 90 dBA and 84 dBA subject groups. The mean C was elevated in both the 84 (+2.91 ug/dl) and 90 dBA (+6.02 ug/dl) groups 24 hours after the onset of noise. The 90 dBA subjects had been out of the noise for 16 hours, but still exhibited a significant increase (P .05) from the previous days' 9 a.m. sample.

CONCLUSIONS

The non-auditory effects of low frequency noise exposure in humans seem consistent with those recently reported at higher frequencies. The changes observed in this study are conservative as the only stressors were the constant noise and 3 venipunctures. The potential for intermittent/unpredictable noise, task demands and other distractions to increase these somatic responses has been well documented in other studies. Whether the cortisol elevation in both the noise groups, and the blood pressure trend of the 90 dBA subjects, would have persisted or increased with repeated exposure is not known.

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NOISE SENSITIVITY AND PSYCHIATRIC DISORDER IN A COMMUNITY SAMPLE.

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INTRODUCTION

In large field studies excessive noise exposure has not been demonstrated to be a significant cause of mental illness. Noise sensitivity has been associated with psychiatric disorder (Tarnopolsky & Morton Williams, 1980), with neuroticism (Broadbent, 1972), and with predisposition to depression (Lindegaard & Nystrom, 1975). P?st studies of the association of noise sensitivity and psychological disorder have either not examined representative population samples or have not used standardised measures of psychological disorder. These deficiencies were overcome in the present study by interviewing a community sample of women of high and low noise sensitivity followed up from the West London Survey of Noise and Psychiatric morbidity, using the Present State Examination (Wing, 1974) to measure psychological disorder.

MATERIAL AND METHODS

The sample of subjects interviewed in this study was drawn from the 1977 West London Survey of Aircraft Noise and Psychiatric Morbidity (see Tarnopolsky & Morton Williams, 1980 for a full account of the method). The sample was drawn from much of West London and was stratified into two major areas of differing aircraft noise exposure using the Noise and Number Index (a measure of aircraft noise devised and measured by the Civil Aviation Authority comprised of perceived noise intensity in decibels and frequency of exposure to aircraft noise). The high noise zone close to Heathrow Airport was exposed to greater than 45 N.N.I. while the peripheral low noise zone was exposed to less than 45 N.N.I. The "self-report question" using a 3-point scale and the "list of 7 annoying noises" derived by McKennell (1963) from work by Bennett (1945) were used to define groups of highly noise sensitive (HNS) and low sensitive (LNS) subjects from the 1977 sample in order to maximise the expected differences between noise sensitive and insensitive subjects. A sample of women between the age of 18 and 50 years, in

1977, born in Britain, were interviewed excluding those with gross hearing impairment.

Subjects were contacted through Social and Community Planning Research and asked to cooperate in a study of health and the environment. All subjects were interviewed at home by one interviewer (S.A.S.) who was blind to the subject's noise sensitivity as measured in 1977. 16% of subjects questioned after the interview remembered that the previous interview in 1977 involved noise. The present interview began with questions about general health and use of health services, then various physiological measures were taken followed by the General Health Questionnaire and the Present State Examination. The noise sensitivity measures were then taken beginning with the self-report question and McKennell's list of annoying noises. This was followed by a questionnaire containing 11 items drawn from Weinstein's (1978) Noise Sensitivity Scale relating to concentration in noisy situations, tolerance of noise and desire for quiet and privacy and the Personal Sensitivity section of the General Noise Questionnaire (Anderson, 1971) measuring the interference of noise on the enjoyment of everyday activities. These two longer questionnaires measuring noise sensitivity were included to compare with the shorter McKennell and Self Report measures. Finally, there was a section on annoyance followed by measurement of hearing thresholds using a portable audiometer.

RESULTS

217 women fulfilled the study criteria, but 71 had moved out of the study area. Of the remaining 94, 77 were successfully interviewed and 17 refused. The sample contained 34 low sensitives (16 in low noise, 18 in high noise), and 43 high sensitives (23 in low, 20 in high noise) as measured in 1977. From 1977, low sensitives (LNS) were defined as those who were both "less" sensitive on self-report and scored up to 2 on McKennell's scale. High sensitives (HNS) were those who were "more" sensitive on self-report and scored 5, 6 or 7 on McKennell's scale.

Association of the Noise Sensitivity measures

In 1980 the Self Report and McKennell measures were still strongly associated ($p<.001$), particularly in high noise conditions. 66% of those answering in 1980 gave similar responses to both sensitivity questions (irrespective of their response in 1977), and this percentage was higher (76%) in the high noise area.

Self-report sensitivity was associated both with the Anderson's Personal sensitivity (ANOVA, $F=9.78$, d.f. 2, 74, $p<0.001$) and with the abbreviated Weinstein questionnaire (ANOVA $F=22.6$, d.f. 2, 74, $p<0.001$). These associations were not affected by noise zone.

The McKennell's list of annoying noises was associated with Anderson's questionnaire (ANOVA, $F=17.7$, d.f. 2, 74, $p<0.001$) and correlated with the Weinstein questionnaire (Pearson correlation coefficient = .6537 $p<0.001$).

The Anderson questionnaire also correlated with the Weinstein questionnaire (Pearson correlation coefficient -.6327 $p<.001$ where high negative Anderson score = HNS).

Association between Noise Sensitivity measures and P.S.E.

Table 1 - P.S.E. mean symptom scores

	Noise Sensitivity			
	Low	Medium	High	ANOVA
McKennell	2.32	5.58	8.77	F=40.7 d.f. 2, 74 p<.001
Self-report	3.35	4.57	7.86	F=3.27 d.f. 2, 74 p<.05
McKennell (high noise)	1.62	4.67	9.84	F=10.1 d.f. 2, 35 p<.001
" (low noise)	3.83	6.00	7.75	F=2.24 d.f. 2, 36 n.s.
Self-report (high noise)	1.82	3.80	8.95	F=6.66 d.f. 2, 35 p<0.01
" (low noise)	5.22	6.50	7.00	F=0.16 d.f. 2, 36 n.s.

Mean P.S.E. symptom scores were significantly higher among HNS individuals for both the McKennell and Self Report measures. This association was confirmed using the PSE "Index of Definition", a 9-point scale of the probability of a subject being a case of psychiatric illness. Two different thresholds were employed, 5+ were possible cases, and 6+ were confirmed cases.

P.S.E. possible caseness was significantly associated both with HNS on the McKennell list of annoying noises (X^2 $p<.001$) and self report sensitivity (X^2 $p<.05$). A similar pattern was found for the other Noise Sensitivity measures, the Anderson and the Weinstein Scales. The Anderson questionnaire was significantly associated with P.S.E. possible caseness (ANOVA F=4.48 d.f. 1, 75 $p<.038$). High sensitivity on the Weinstein scale was also significantly positively associated with P.S.E. possible caseness (ANOVA F = 7.864, d.f. 1, 74 $p<.006$). As there were only 6 confirmed P.S.E. cases in this general population sample it was not surprising to find a non-significant association with the noise sensitivity measures.

The associations between the P.S.E. and the self-report and McKennell measures were also examined separately for the high and low noise areas. These associations remained significant in the high noise area for both P.S.E. symptom scores and possible caseness but lost significance in the low noise area.

DISCUSSION

The association between **noise sensitivity and** psychiatric disorder has

been confirmed using both P.S.E. mean symptom scores and index of definition. Consistent association between the four measures of noise sensitivity supports the evidence for noise sensitivity as a distinct entity and the association of the Weinstein and Anderson noise sensitivity measures with the P.S.E. measures adds weight to the findings with the McKennell and Self Report. In a general population sample noise sensitivity might be expected to be related to minor symptoms of anxiety and depression as was found rather than with confirmed psychiatric caseness.

The differential association with the P.S.E. between high and low noise areas may be explained two ways. Subjects exposed to high noise showed greater consistency in their self assessment of noise sensitivity (as evinced by more consistent association of the noise sensitivity measures) than subjects in low noise and as such their assessments of noise sensitivity may be more accurate than those in low noise.

Secondly, these results would fit with the hypothesis that high noise exposure leads to the expression of psychiatric symptoms of depression and anxiety in highly noise sensitive subjects; subjects in the low noise area, despite their high noise sensitivity, would not be expected to demonstrate this association with psychiatric morbidity. This study lends support to the general hypothesis of stress (noise) acting on a predisposed, vulnerable individual (highly noise sensitive) to cause psychiatric morbidity.

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ACKNOWLEDGEMENTS

I wish to thank Professor M. Shepherd, Dr. A. Tarnopolsky, Dr. C. Clark, and L. Jenkins.

INFLUENCE OF INDUSTRIAL INFRASONIC NOISE ON NERVOUS SYSTEM.

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INTRODUCTION

Most investigations concerning the influence of infrasound on man has been performed with the infrasonic noise of arbitrarily chosen parameters. The aim of our study was to measure varoius psychophysiological data in humans during the exposition to infrasonic noise, with parameters beeing possibly close to those eccountered in natural work condition in industry.

MATERIAL AND METHODS

In our experiments participated 10 healthy paid volunteers in age from 20 to 29 years. All of them a written instruction were given and no other comments were supplied during the experiment. All the participants filled in Eysenck Personality Inventory /EPQ/.

The infrasonic noise was tape-recorded in a factory in Warsaw. The source of the noise was an air-compressor. The record was then replayed in the infrasound cabin in our laboratory. /Fig.1/. The cabin /200x120x70 cm/ was built of 20 mm hardboard plates. The infrasound was generated by six low-tone loudspeakers of 360 Watt total power. The cabin was provided with an air-condition, intercom, microphone, electrode-board for Grass- polygraph, light, swith of the amplifier and a window. The subjects were placed in an armchair

in an comfortable position. Before and after each experiment a tonal threshold audiometry and brain stem auditory evoked potentials were performed. Moreover in six subjects blood samples for free fatty acids were taken. Each experiment lasted 1 hour. After 50 min. subjects were asked to perform a psychological test for eye-hand coordination /a labyrynth/ then 30 reaction times were measured. During the whole experiment following parameters were recorded: electrocardiogram /lead I/, electroencephalogram /Cz-Oz, Cz-A1, Cz-A2/ and skin temperature. Artifacts were controlled by means of recording signals from 10 kOhm resistor, placed on the head and connected to the amplifier similarily like EEG leads. Each subject participated in two experiments with 1 hour rest outside the cabin. In one experiment subjects were exposed to infrasound in the other they were sitting in silence. The sequence of experiments were changed in order to exclude the influence of fatigue. All the measurement in silence and during the exposition to infrasound then were compared.

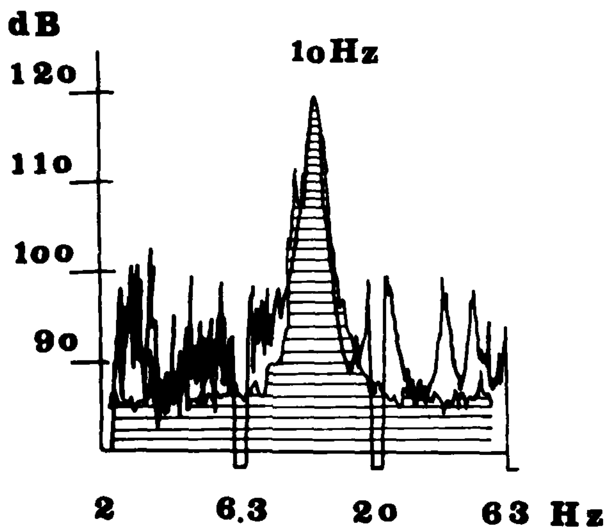

Fig. 1 - Spectrum of infrasonic noise recorded in the factory - thick line, and replaye in the laboratory - shaded area.

RESULTS

There was no relationship between personality questionnaire scores and other results. In 7 subjects after the expo-

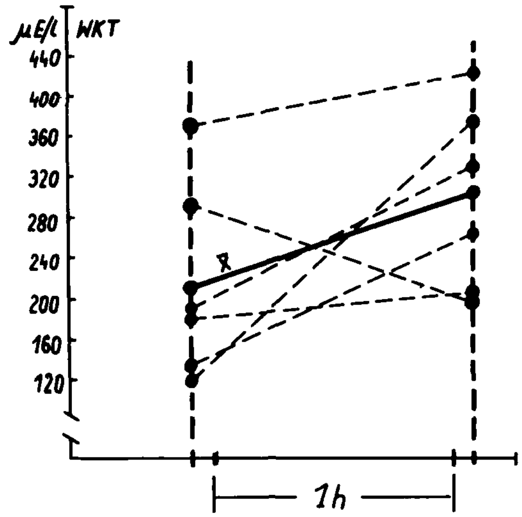

Fig. 2 - Level of free fatty acids in 6 subjects and me
value in blood before and after the exposition
infrasonic noise.

sition to the noise a slight threshold shift /TTS/ was considered in audiogram /from 5 to 10 dB/. Brain stem auditory evoked potentials did not differ in any case. In 5 subjects the level of free fatty acids in blood was increased after the exposition to the noise /mean increase - 37%/. /Fig. 2/. Only in one person it was decreased after exposition, but just this subject fell asleep during this experiment /sleep stage 4 as revealed by EEG record/. This was the only case of sleep during the exposition to the noise. However sleep was observed in 3 subjects in silence. EEG record did not reveal any difference between silence and the noise. Heart rate did not differ in noise and silence. It was only increased in some persons during the psychological testing. Skin temperature decreased during the exposition to the noise in 8 subjects. In silence it decreased only in 4 subjects. Reaction time increased in all subjects during the exposition to the noise. In 8 persons it was highly significant. Mean increasing of

the reaction time for the whole group was 366 ms which was highly significant /t=5.3 p .001/. In silence the reaction time was different from person to person but in the whole group it was only slightly decreased. The test for eye-hand coordination did not reveal any difference.

CONCLUSIONS

Our results did not show any changes specific for infrasound. TTS was only slight, but it was also observed by others /Nixon and Johnson 1973/. The decrease of skin temperature was reported by Wysocki et al. /1980/. The increase of the reaction time was yet reported by Leventhall /1973/. Our conclusion is in accord with Borredon /1980/ that the influence of infrasound is nonspecific and depends on action of neurohypophyseo,adrenal function.

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EFFECTS OF NOISE ON THE CARDIOVASCULAR SYSTEM: APPRAISAL OF EPIDEMIOLOGIC EVIDENCE.

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INTRODUCTION

Studies of the extra-auditory health effects of noise have been contradictory. The major objectives of this analysis were (1) to critically evaluate the extant world literature as to whether or not long-term exposure to noise is detrimental to cardiovascular health and (2) to make recommendations for future epidemiologic studies of the effects of long-term noise exposure on the cardiovascular system.

MATERIAL AND METHODS

After a careful search of the international literature, 36 studies reported in English language journals and 47 in the non-English literature were critiqued independently by an epidemiologist, audiologist, and cardiologist. Major conclusions were derived by the review team and consultants. Noise factors considered were description, instrumentation, measurement environment and procedure, and quality of data about subjects. Cardiovascular effects were judged by the quality of diagnostic criteria used, documentation of pre-existing disease and the natural course of the health/disease state. Epidemiologic criteria included adequacy of study design, sample size and statistical analysis; strength of the association; temporal relationship of noise to health

outcomes; evidence of a dose-response; and control of confounding variables. Problems identified included inability to document direct noise exposures of individuals; failure to describe cumulative long-term exposure; use of widely varying noise levels; failure to use standard blood pressure (BP) measurements and to report the full distribution of BP; failure to use multiple regression and adjustment techniques to account for strong risk modifiers and confounders.

RESULTS

Three major findings emerged from the literature analysis. Firstly, studies to date are inadequate for establishing cause-effect relationships and for estimating the risks of cardiovascular disease due to noise exposure. Of the 83 studies, 66 were cross-sectional in design, providing the weakest evidence from which to infer cause since it was not possible to determine that noise exposure preceded an increase in BP or the onset of disease. Overall, the studies were of relatively poor quality.

Secondly, the strongest evidence of an association, if one exists, is between exposure to high noise and elevated BP. No specific patterns of response to noise emerged from studies of heart rate, cholesterol and B-lipoproteins, electrocardiographic changes and cardiovascular disease death rates. Two of three prospective studies showed no association between noise exposure and elevated BP. The cross-sectional studies were consistent (44 of 55) in finding elevated BP to exist among persons exposed to high noise. However, the differences in mean systolic blood pressure between the high and low noise groups were small (about 5-10 mm Hg) with non-English studies consistently reporting the larger differences. Prevalence ratios for hypertension

between the high and low noise groups ranged from 1.6 to 2.8 (to 6.4 for special groups). No study was identified which allowed a reasonable estimate of risk based on incidence data. Seven studies suggested a dose-response relationship between noise exposure and BP changes; five research teams reported an increase in prevalence of hypertension with an increase in length of employment. The literature offered little and conflicting evidence as to the influence of hearing protection on the reduction of the effects of noise on BP. One researcher reported that hearing protection reduced the daily noise level by 10-16 decibels (dB). At a mean exposure to noise of 95 dB, the systolic BP of subjects working without hearing protection was higher by almost 7 mm Hg than when the same subjects worked with ear protection.

Finally, it was determined that the body of data provides sufficient evidence to support further research of the effects of noise on the human cardiovascular system, especially the effects of long-term exposure to high noise on blood pressure.

CONCLUSIONS

Recommendations for future epidemiologic research of the effect of noise on the cardiovascular system include:
(1) priority should be given to designs which offer the strongest evidence for causal associations such as synthetic retrospective-cohort studies in occupational groups exposed over long periods to high noise, large retrospective-cohort studies with continued followup in groups exposed to varying

levels of industrial noise and with followup in selected samples of the general population, and randomized intervention trials in industrial settings. (2) Future studies should estimate required sample sizes in advance, control for confounding variables and adopt sophisticated analytic techniques currently available. A position paper on statistical methods for noise research should be developed with consideration given to the application of Mantel-Haenszel procedures, regression/covariance analysis, logistic analysis and Cox's proportionate hazards model (which allows for use of followup data of varying lengths of time for different individuals) to noise effects data. (3) Any large scale study should be preceded by an indepth planning phase. (4) Collaboration of scientists among countries should be encouraged to increase the sharing of ideas and to reduce time required for new techniques to be applied in noise effects research.

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ACKNOWLEDGEMENTS

I wish to thank Drs. D.B. Propert, F.D. McDonald, J. Keil, K. Jackson, H.A. Tyroler, D.M. Lipscomb, R. Massey, and D.M. DeJoy and Ms. J. Johnson for their expert assistance.

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